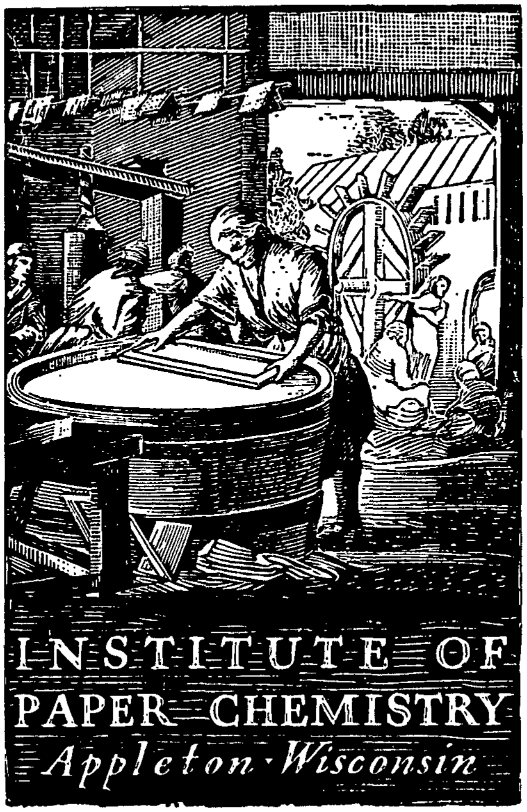
M. Lorenz

GENERAL



COMPARATIVE EVALUATION OF METHODS OF EVALUATING EDGEWISE COMPRESSION STRENGTH OF CONTAINERBOARD

Project 2694-13

A Summary Report
to
FOURDRINIER KRAFT BOARD GROUP
of The
AMERICAN PAPER INSTITUTE

July 15, 1977

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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TABLE OF CONTENTS

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SUMMARY

The edgewise compression strength of linerboard and corrugating medium is one of the most important properties governing top load box compression strength. For this reason a number of methods for measuring this property have been developed over the years. In general, the results obtained using the various methods differ to a considerable extent and this has caused concern as to the most appropriate method to employ for quality evaluation. The older methods, such as the ring compression or Concora liner test (CLT), were developed to measure the maximum compression strength of the board. More recently, tests of the lateral support type have been developed by the Forest Products Laboratory and the Weyerhaeuser Company to provide means for evaluating the compressive load-deformation characteristics of paperboard up to compressive failure, i.e., maximum load.

Accordingly, this study was undertaken to comparatively evaluate six methods of measuring the cross direction edgewise compression strength of linerboard and corrugating medium. The methods were compared in terms of maximum load, test variability, correlation to combined board edgewise compression strength, correlation to each other, and relative ease of testing. The compression test methods studied were as follows:

1. Regular ring crush test
2. Modified ring crush test
3. Liner edge crush test (LECT) — similar to Concora liner test but with Weyerhaeuser Company upper holder
4. Concora fluted crush (CFC) — medium only

5. Forest Products Laboratory (FPL) lateral support compression test

6. Weyerhaeuser Company lateral support compression test.

In the FPL test the 1 × 2.55-inch specimen is clamped at top and bottom and the middle portions of the specimen are supported by the flat steel faces of the holder. In the Weyerhaeuser lateral support test, the dumbbell-shaped specimen is also clamped at top and bottom, but is supported between the clamps by a number of spaced blades on each side of the specimen.

For comparison purposes a wide array of linerboards and mediums were evaluated by each of the six tests. In addition, the compression results obtained on the component materials were correlated with short column test results on combined boards fabricated from the various linerboards and mediums.

The following results were obtained:

1. Comparison of maximum loads — linerboard

   a. For the tests on linerboard carried out on the H&D compression tester the highest maximum loads were achieved with the modified ring test due to the more favorable mode of failure. On linerboard the regular ring and LECT maximum load results averaged 15 and 32.5% less than the loads obtained with the modified ring test.

   b. The maximum loads on linerboard obtained with the Weyerhaeuser lateral support test averaged 19.5% lower than the maximum loads obtained with the FPL lateral support test. However, the Weyerhaeuser results were in close agreement with modified ring compression results when they were tested at approximately equal strain rates on the Instron tester. In the FPL lateral support test the specimen may be in partial contact over much of the test area because the sides of the holder are only relieved by 0.001 inch. Thus, frictional effects may be introduced which would add to the apparent load at failure (and also affect stress-strain properties).

2. Comparison of maximum loads — medium

   a. For the tests on medium carried out on the H&D compression tester, the highest maximum loads were achieved with the Concora fluted crush (CFC) test — in part due to the drying of the specimen during fluting. The CFC results averaged 7.4% higher than the modified ring results and the regular ring compression results averaged 36.1% lower than the modified ring results.

   b. The maximum loads obtained with the Weyerhaeuser lateral support test averaged 28.0% lower than the results obtained with the FPL lateral support test. However, clamping and frictional effects in the FPL test may be responsible in part for this difference as mentioned previously.

3. Comparison of Test Variability

   The comparisons of test variability indicated that the modified ring test was least variable, followed by the regular ring test, the LECT/CFC combination, the FPL test and the Weyerhaeuser test. Both the FPL and Weyerhaeuser tests, however, operate on a much narrower specimen (approximately 1/6 as wide) and would be expected to be more variable since less material is present for "averaging."

4. Correlation with combined board edgewise compression strength

The multiple correlation coefficients between the various tests and combined board edgewise compression strength are summarized below

Test	Within Series Multiple Correlation Coeff. Max.	Within Series Multiple Correlation Coeff. Min.	Overall Correlation
Reg. ring	0.89	0.69	0.98
Mod. ring	0.96	0.50	0.98
LECT/CFC	0.97	0.44	0.97
FPL lat. supp.	0.97	0.71	0.98
Weyerhaeuser lat. supp.	0.97	0.71	0.98

In general, the "quality control" tests (regular ring and LECT/CFC) correlated about as well with combined board edgewise compression as any of the other tests. The LECT/CFC combination had a somewhat higher maximum within series correlation than the regular ring. However, the minimum coefficient of 0.44 obtained with the LECT/CFC combination on 200-lb series samples was lower than any of the other coefficients. It is speculated this may be partly due to caliper differences between the various linerboards tested.

5. Ease of testing

The tests run on the H&D compression tester (regular ring, modified ring, LECT and CFC) are quicker and simpler to conduct than the tests run on the Instron (FPL and Weyerhaeuser). That makes them more suited to quality control work since the tests are less expensive. The test equipment is also easier to operate and less expensive to purchase. The extra time involved in specimen preparation for the modified ring test is a deterrent to its use for quality control.

6. Compression modulus and maximum strain

A limited comparison of compressive moduli indicated that the C.D. modulus values obtained with the Weyerhaeuser lateral support test were 22.5% lower than the FPL lateral support results on the average. The strains at failure in the Weyerhaeuser test averaged 31.6% lower than in the FPL test. Thus substantial differences in results are obtained with the two tests. It is possible this may be due to the frictional effects mentioned above in regard to the FPL test. However, further study would be required to clarify the reasons for these differences.

7. Overall conclusions

In general, the regular ring and LECT/CFC tests have advantages for quality control purposes considering they are the easiest tests to use and relate well to the edgewise compression strength of combined board. The ring test correlations to combined board edgewise compression appeared to be somewhat more consistent than the LECT/CFC correlations. However, the LECT test can be provided with the capability to correct for specimen moisture content. This feature should be developed for the regular ring test. It is possible that the correlation of the LECT test to combined board edgewise compression could be improved with the use of different specimen upper holders based on board caliper ranges.

Until the question of frictional interference between the specimen and the sides of the FPL fixture can be resolved, it appears that the Weyerhaeuser lateral support test is the one most suitable for research purposes.

INTRODUCTION

Previous work at The Institute of Paper Chemistry (1) and in industry has shown the importance of combined board edgewise compression strength on the box compression performance of corrugated containers. Combined board edgewise compression strength is primarily related to the individual compressive strengths of the liners and medium used to make the combined board. Consequently, much attention is being directed at the measurement of the intrinsic compressive strength of linerboard and medium for both quality control purposes and for basic research. This attention has led to the design and development of several new methods for measuring the edgewise compression strength of paperboard during the past few years. One method, the Liner Edge Crush Test (2), is an improvement over an existing test, the Concora Liner Test (CLT). Two others are completely new tests developed by the Forest Products Laboratory and the Weyerhaeuser Company featuring lateral support of the specimen to prevent buckling failure (3,4). This project was initiated to compare these new tests with existing tests.

The comparison was conducted using a wide array of components and the combined boards made therefrom. Criteria for comparison included maximum strength, test variability and ease of test usage. Investigations were made regarding the suitability of each test for quality control work or as a basic research tool. A special evaluation of the ring crush tests was made at a strain rate (i.e., rate of specimen loading) nearly equal to the strain rate of the lateral support tests in order to allow a more direct comparison of maximum loads. Finally, all tests were correlated to combined board edgewise compression to see how well each test could be used to predict combined board failure.

This report presents the results of the comparison between the regular ring test, modified ring test, Liner Edge Crush Test (LECT-on liners), Concora Fluted Crush test (CFC-on medium), Forest Products Laboratory lateral support test, and Weyerhaeuser lateral support test.

TEST METHODS EVALUATED

REGULAR RING CRUSH TEST

The regular ring crush test used in this project is described in TAPPI Standard T 818 os-76. The test consists of a die-cut 1/2 × 6-inch specimen of the board inserted into a grooved circular holder and tested for maximum compression load on an H&D Compression Tester at a loading rate of 25 lb/sec. The holder and specimen are shown in Fig. 1. The test yields only maximum load value at failure.

MODIFIED RING CRUSH TEST

The modified ring crush test is a variation of the regular ring test developed at The Institute of Paper Chemistry a number of years ago (5). The holder for liner samples having basis weights of 40 lb/M ft^2 or more is the same as that for the regular ring. The specimen is cut in the same die as the regular ring, but is formed into a fixed cylindrical shape through the use of contact cement on the overlapping ends. This helps to reduce the buckling failure of the unfastened ends on the regular ring. In addition, the top and bottom edges of the specimen are dipped in wax before forming the cylinder, providing reinforcement that eliminates the edge crush effect that occurs in the regular ring test. Finally, a special small diameter holder and a 2-inch long specimen are used for mediums and liners up to 40 lb/M ft^2 basis weight. This provides additional stiffness for the lower caliper boards. Both holders and their respective specimens are shown in Fig. 2. The test is conducted on the H&D tester at a loading rate of 25 lb/sec (identical to the regular ring) and the maximum load at failure is obtained.

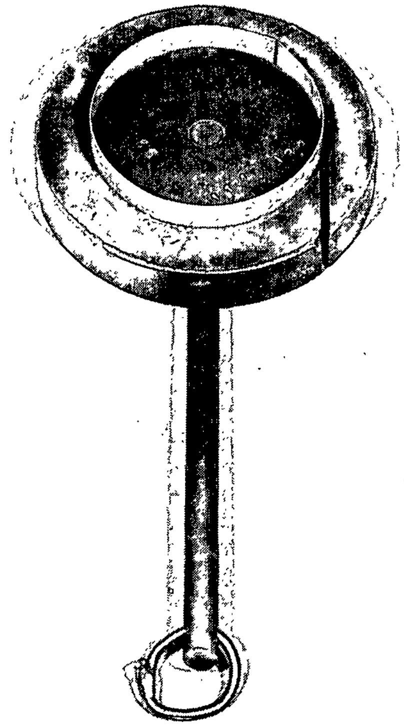

Figure 1. Regular Ring Crush Test

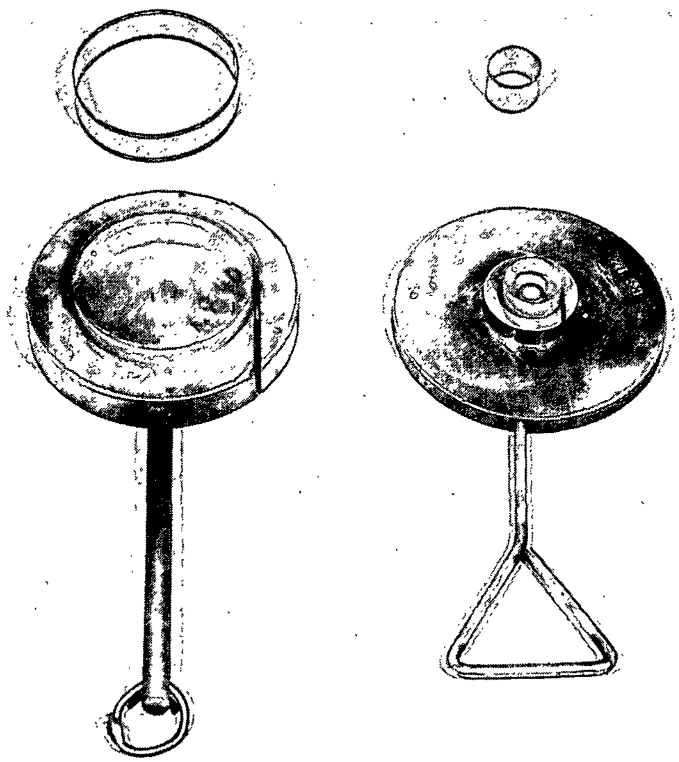

Figure 2. Modified Ring Crush Test

LINER EDGE CRUSH TEST (LECT)

The Liner Edge Crush Test (LECT) (2), is a Weyerhaeuser variation of the Concora Liner Test (CLT) as originally developed by the Container Corporation of America and reported on by Maltenfort (6). The specimen is die-cut in the same cutter as the regular ring specimen. It is then clamped in a scissors-type holder which is inserted into a special fixture attached to the load beam (lower platen) on an H&D tester.

In the original CLT test, a flat upper platen was employed. Later, in an effort to reduce the effect of specimen curl, Maltenfort (6) discussed use of a special upper platen incorporating a straightening bar to reduce specimen curl and bending.

The Weyerhaeuser modification consists of the addition of a grooved upper platen which is also intended to reduce the effect of curl and bending of the specimen. The test apparatus is shown in Fig. 3. The loading rate of the H&D tester is 25 lb/sec and the test result is a maximum load reading. This test is designed for linerboard only and is considered a companion to the Concora Fluted Crush Test (CFC) which is for medium only.

Another potential LECT improvement over the CLT is the installation of an electronic device to compensate for moisture in the specimen during testing. While this system was not evaluated in this project, it is worth noting because it does affect the suitability of the LECT for quality control work in the mill with unconditioned samples.

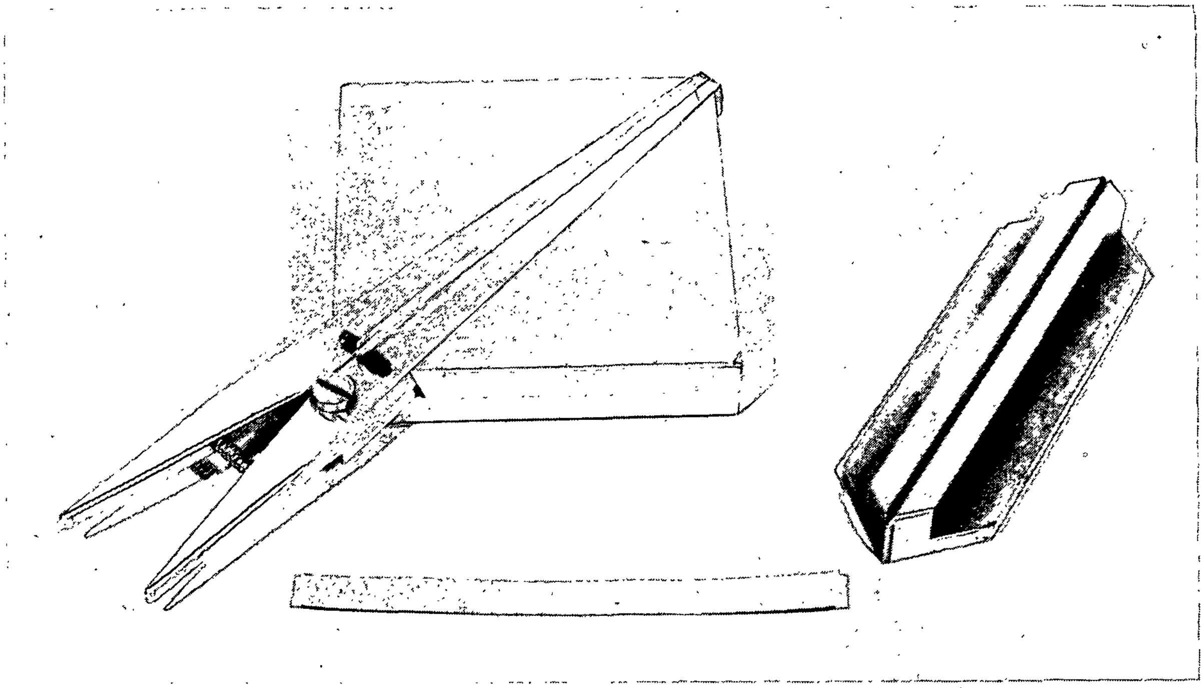

Figure 3. Liner Edge Crush Test (LECT)

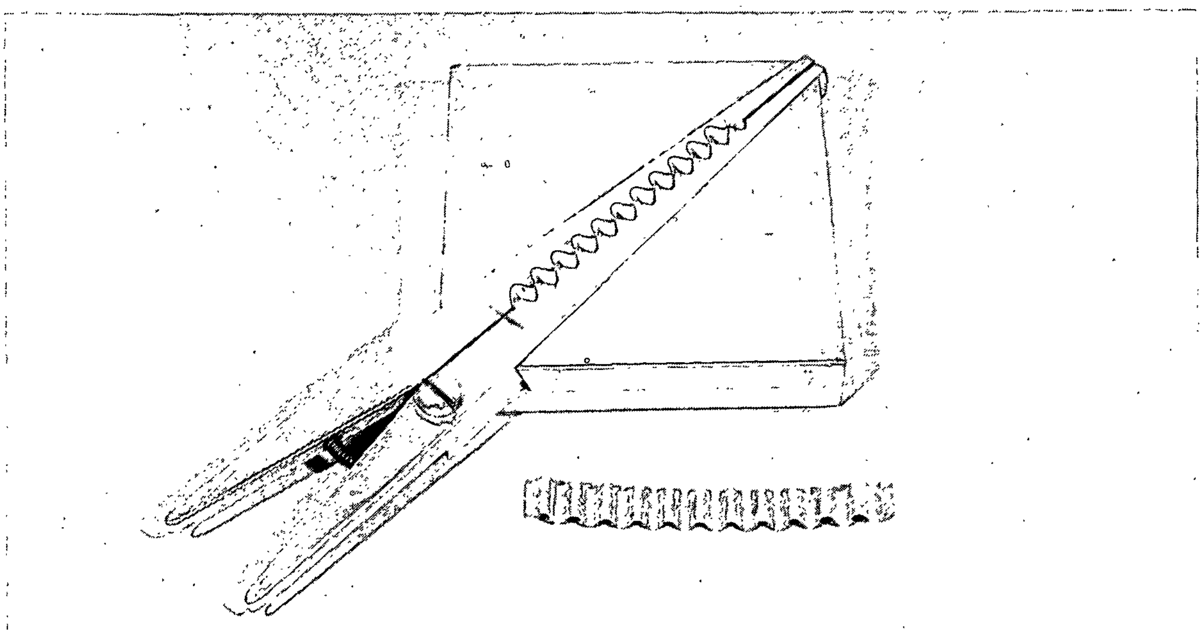

Figure 4. Concora Fluted Crush Test (CFC)

CONCORA FLUTED CRUSH TEST (CFC)

As mentioned previously, the Concora Fluted Crush test is used exclusively on medium. It is a companion test to the LECT and was included in this project to complement the LECT results on linerboard. It was originally developed by the Container Corporation of America and uses the same fixture on the lower platen of the H&D tester that the LECT uses. This can be seen in Fig. 4. The scissors-type specimen holder, however, has a fluted opening to hold the medium. The medium must be prefluted on a Concora fluter and then immediately tested. The fluting operation causes some heating and drying of the specimen and, hence, the specimen is not in moisture equilibrium with the test atmosphere at time of test. The specimen size is the same as that of the regular ring and LECT. A flat upper platen is used on the H&D tester because the fluted shape provides stiffness that eliminates curl and buckling. Loading rate is 25 lb/sec and the test result is a reading of maximum load.

FOREST PRODUCTS LABORATORY LATERAL SUPPORT TEST

The Forest Products Laboratory (FPL) Lateral Support Test is shown in Fig. 5. It is designed to provide support to the specimen to prevent buckling during compression loading. A 1 × 3-inch specimen is clamped in the tester with a spacer inserted between the top and bottom tester halves to keep them separated vertically. The clamping is achieved by tightening four screws in sequence to torques of 1, 3 and, finally, 5 inch-lb. The area between the clamps is relieved by 0.001 inch on each side to provide clearance for the specimen while simultaneously providing for support against buckling. This is shown schematically in Fig. 6. The cuts between the top and bottom halves of the tester are made on a diagonal to insure support of the specimen over the entire span between the clamps. After

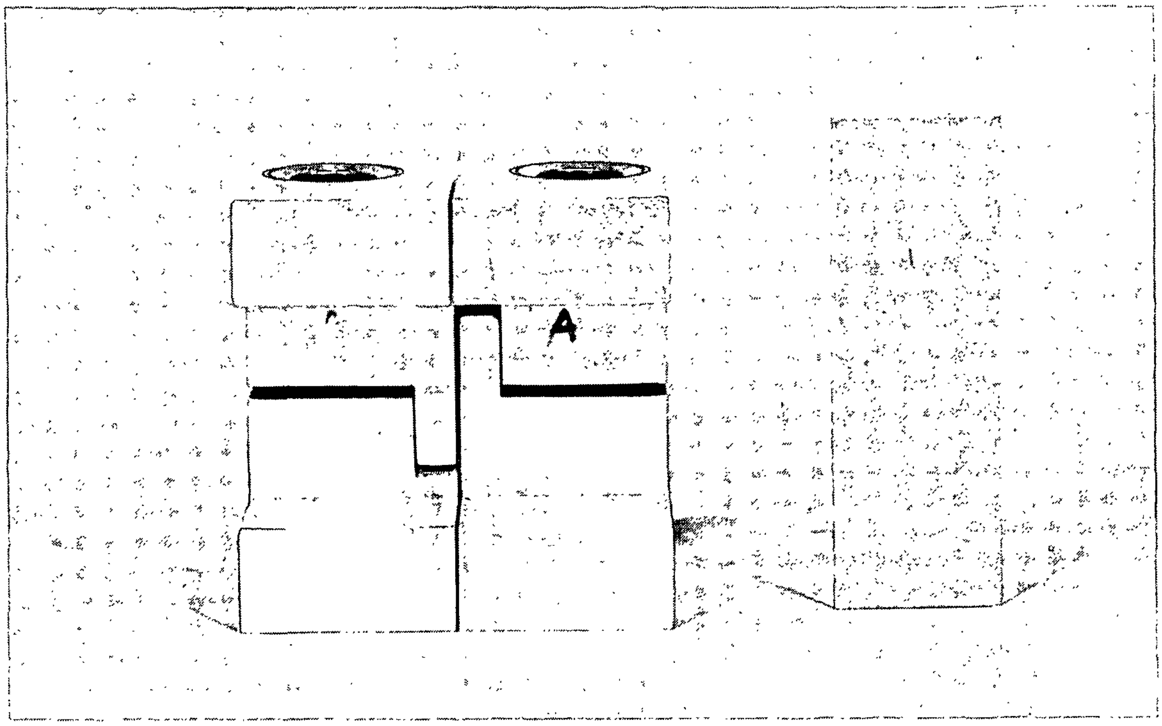

Figure 5. Forest Products Laboratory Lateral Support Test

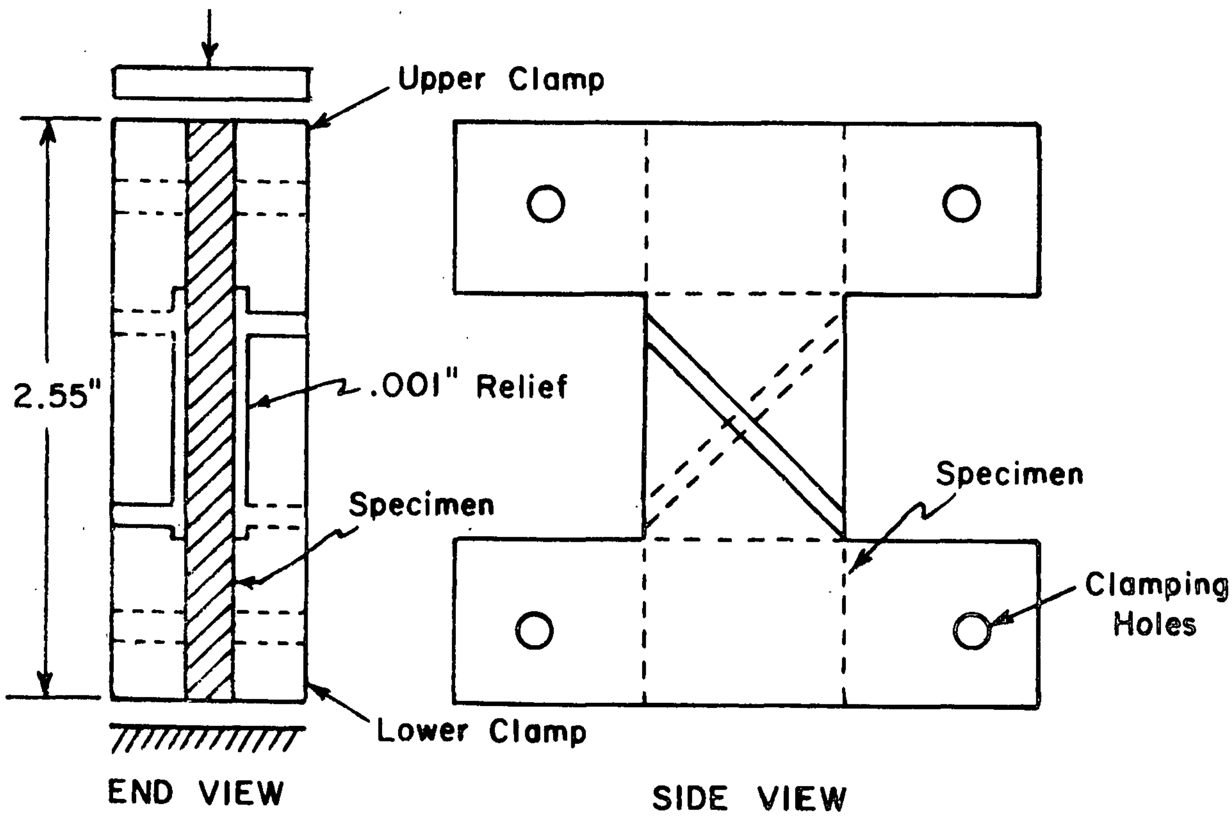

Figure 6. Schematic of FPL Lateral Support Design

clamping, the top and bottom of the specimen are shaved flush with the top and bottom of the tester, the spacer is removed, and the assembly is inserted into a compression test machine. An Instron or similar compression tester is employed when load-deformation curves are desired. The recommended platen rate of travel is 0.02 inch/min. This is equivalent to a strain rate of 0.015 inch/inch/min (specimen span = 1.33 inches). A special spherical loading head is also recommended to provide a pure compression load with no applied moments. If load-deformation curves are not required, an H&D compression tester may be employed, in which case the spherical loading head is omitted.

WEYERHAEUSER LATERAL SUPPORT TEST

The Weyerhaeuser Lateral Support Test (also referred to as Weyerhaeuser test in text) is designed to provide support to the specimen during compression testing by a system of spring steel blades (support comb) brought to bear against the specimen under controlled pressure. The tester is shown in Fig. 7, and a schematic representation of the steel blades and specimen dimensions are shown in Fig. 8. The specimen is die-cut for exact dimensions and is dumbbell shaped to insure failure in the narrow region and away from the clamping area. The spacing between the steel blades of the comb is varied depending on the specimen caliper. Five comb pairs are designed to be used according to the following table:

Blade Spacing, mm	Appropriate Specimen Caliper, pt		
	SR = 10	SR = 20	SR = 30
1.0	13.6	6.8	4.5
1.2	16.3	8.2	5.4
1.5	20.4	10.2	6.8
2.5	34.1	17.0	11.4
3.25	44.3	22.1	14.8

Note: SR = slenderness ratio.

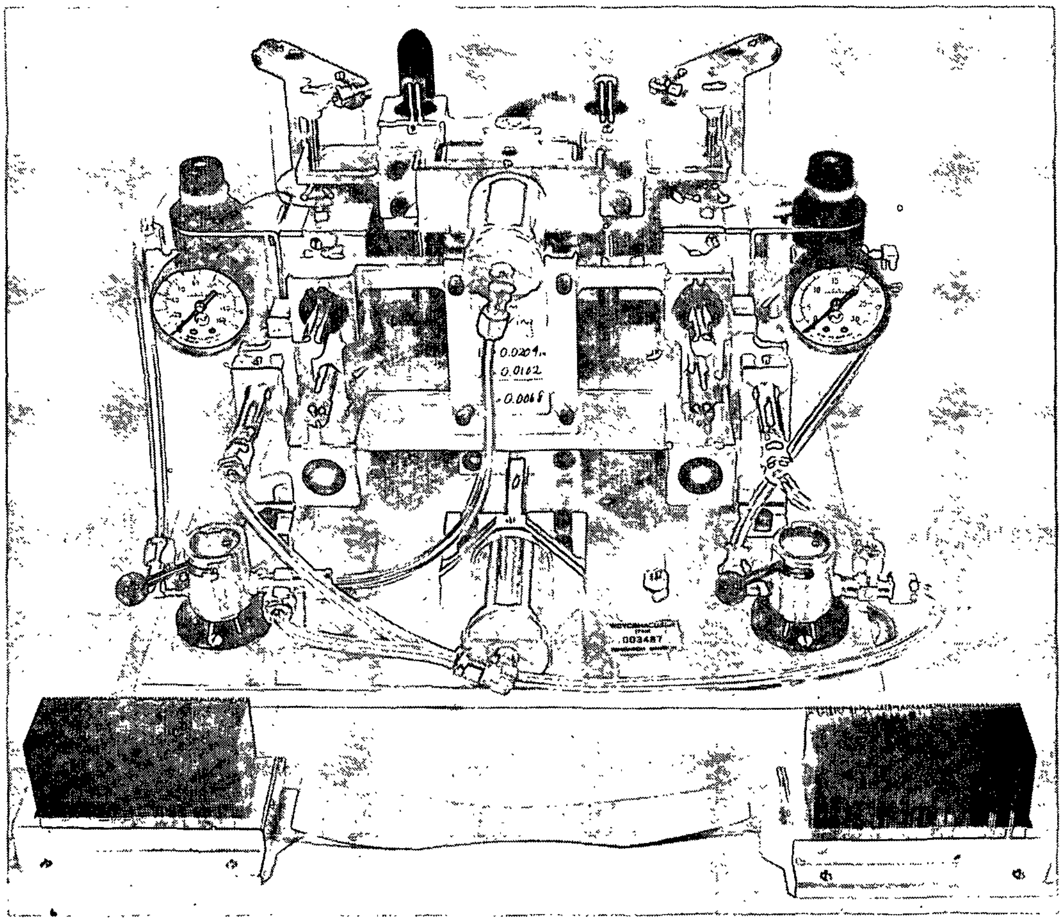

Figure 7. Weyerhaeuser Lateral Support Test

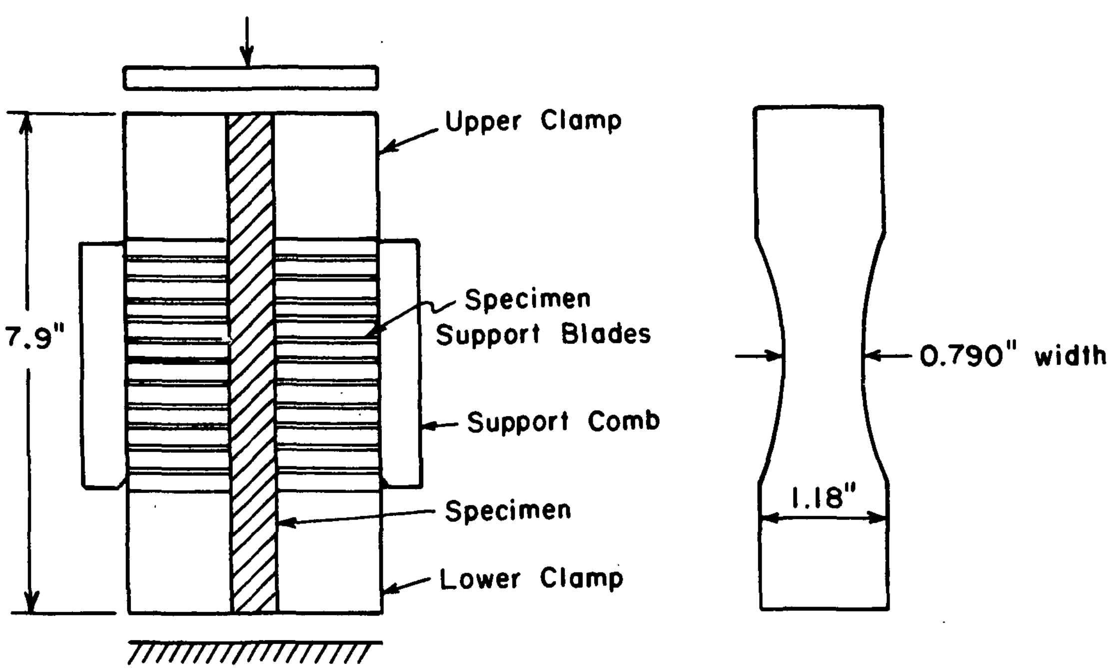

Figure 8. Schematic of the Weyerhaeuser Lateral Support Design and Specimen Shape

For a given caliper, the comb set having a spacing that produces a slenderness ratio near 20 is preferred. The combs are easily interchanged.

In operation, the specimen is inserted vertically through an opening in the top of the tester. A manual air valve is actuated to provide top and bottom clamping force via air cylinders. A slight tensile preload is applied to the specimen to take up any curvature and a second air valve is actuated to bring the combs against the specimen. The combs are then locked into position by small screws to prevent them from backing away from the specimen during testing. The tensile preload is removed and the compression test run. A tester such as the Instron must be used since the Weyerhaeuser device is too large for the H&D tester. A loading rate of 0.08 inch/min is used yielding a strain rate of about 0.023 inch/inch/min (effective span = 3.5 inches).

SHORT COLUMN CRUSH TEST FOR COMBINED BOARD

The short column tests (edgewise compressive strength for corrugated board) were conducted for this project in order to provide data with which to correlate the results of the individual component liner and medium tests. These tests were conducted according to TAPPI Standard T 811 os-70.

TEST PROCEDURES

MATERIAL

Fifty-eight samples of C-flute combined board from various manufacturers and associated components of single-face liner, double-face liner and medium were obtained. They were arranged by board series according to the following:

125 lb series	7 samples
175 lb series	8 samples
200 lb series	22 samples
275 lb series	11 samples
350 lb series	10 samples

A detailed listing of basis weight and caliper for each sample and component appears in the appendix along with the individual test results.

Specimens for the regular ring, modified ring, LECT and CFC were all cut on the same die cutter. Specimens for the Weyerhaeuser test were cut on a special die cutter. Specimens for the FPL test were cut on a paper cutter. The combined board specimens were prepared in accordance with TAPPI T 811 for the short column crush test. For each sample lot and test, ten specimens were evaluated.

All testing in this project was done in the cross machine direction.

CONDITIONING

All samples (combined board and components) were preconditioned for 24 hours at 23°C and less than 35% RH. They were then conditioned for at least 48 hours at 50 ± 2% RH and 23 ± 1.0°C prior to testing.

COMPRESSION TESTERS

A standard H&D compression tester operating at 25 lb/sec (upper platen rate of 1.5 inch/min) was used where applicable as discussed in the description of the individual tests. For use with the FPL fixture, the lower beam of the H&D tester was fitted with a displacement transducer connected to an X-Y recorder to provide a visible display of the applied load vs. time.

A table model Instron Load/Elongation Tester was used also where applicable and to provide a series of tests on the regular ring, modified ring, FPL and Weyerhaeuser fixtures at nearly equal strain rates. Because of the limited number of available speeds on the Instron and the differing test spans, it was not possible to select platen speeds which would give the same unit strain rates for all tests. The following rates were employed:

Test	Platen Speed, in./min	Unit Strain Rate, in./in./min
FPL lateral support test	0.02	0.015
Weyerhaeuser lateral support test	0.08	0.023
Ring crush tests	0.01	0.020

The compression modulus and strain values in the lateral support tests were obtained from the load-deformation curves after correcting for instrumental strain effects. In order to determine the strain correction a steel specimen about 0.03 inch thick was clamped in the FPL and Weyerhaeuser fixtures. Load-deformation curves were obtained with the steel specimens over the desired load ranges. The deformations obtained in this way were regarded as a measure of instrumental strain because of the high modulus and stiffness of the steel specimen.

In order to calculate the compression moduli, tangents were drawn to the initial straight line portion of the load deformation curve for each paperboard specimen. The deformation corresponding to a given load on the tangent was then obtained and corrected by subtracting the deformation obtained at that load with the steel specimen. The modulus was then calculated as follows

$$E = PL/Ad \tag{1}$$

where

$\underline{E}$ = modulus of elasticity, psi

$\underline{P}$ = selected load on tangent

$\underline{L}$ = test span, inch

$\underline{A}$ = cross-sectional area, sq inch

$\underline{d}$ = deformation, inch at selected load $\underline{P}$

In the case of the Weyerhaeuser test an effective width of 0.920 inch was employed in accordance with the instructions accompanying the test.

The strain values at maximum load were also corrected, based on the steel load-deformation curves.

DISCUSSION OF RESULTS

The criteria for judging edgewise compression test load results are generally accepted as:

a. The maximum load should be the highest possible with no artificial strengthening of the specimen.

b. Failure of the specimen should be remote from the loading edges (or clamps) but not initiated by bowing or buckling.

c. Moduli of elasticity for tension and compression of the same sample should be equal.

This study did not include evaluation of tensile moduli although the compressive moduli obtained using the FPL and Weyerhaeuser lateral support tests are compared in a later section of the report.

In evaluating the tests for maximum load, a direct comparison of maximum load values could not be made with the tests run as they were designed. In general, the average strain rates for the tests run on the H&D tester were much higher than the strain rates for the tests run on the Instron tester. In addition, the strain rate on the H&D tester is not constant throughout its loading cycle because of the flexible lower beam that is used. Since the failure of paperboard has been shown to be strain rate sensitive, (most strength properties increase as strain rate increases) it was felt that the evaluation should be conducted under both conditions, at unequal strain rates (as the tests were designed) and at strain rates that were as equal to each other as the test machines would allow.

COMPARISON OF MAXIMUM LOAD RESULTS — UNEQUAL STRAIN RATES

As mentioned in the discussion of materials, a large number of samples (58 sets) were evaluated to provide data for good correlation and comparison purposes. The detailed results for the sample components and combined board are included in the appendix arranged by board series. Calculations of averages based on this data are presented in the body of the report for discussion.

Table I shows the average maximum loads obtained at unequal strain rates for the kraft linerboards in each combined board series. To illustrate these results graphically, Fig. 9 was drawn showing the results of the tests run on the H&D tester and Fig. 10 was drawn showing the results of the tests run on the Instron tester with the modified ring results obtained on the H&D tester added for comparison purposes.

Table I and Fig. 9 show that the modified ring compression results were significantly higher than either the regular ring or the liner edge crush (LECT) results. On the average, the modified ring compression results were 15.0% higher than the regular ring and the difference between the tests was highest (28.3%) for the liners (mostly 26-lb basis weight) used in fabricating the 125-lb. series combined boards. These results agree with past work because the regular ring failures usually involve crushing at the edges and/or buckling in the lighter weight samples. The LECT results were 32.5% lower than the modified ring results on the overall average and, again, the differences were most extreme for the lighter weight liners. The LECT results for the liners used in the 125-lb. board series were 70.0% lower than the modified ring results. The difference between the tests gradually decreased as the liner weights increased, and the LECT test results for the liners used in the 350-lb. board

TABLE I

COMPARISON OF MAXIMUM LOAD LEVELS ON LINERBOARD
(Unequal Strain Rates)

Average maximum load, lb/inch

Board Series	No. of Samples	Liner Weight, lb/M ft²	Facing Pos.	Reg. Ring Comp.[c]	Diff., %[a]	Mod. Ring Comp.[c]	Liner Edge Crush[c] (LECT)	Diff., %[a]	FPL Comp.[d]	Diff., %[a]	Weyer-haeuser Comp.[d]	Diff., %[a]	Diff., %[b]
125	7	26-33	S.F.	8.8	--	12.1	3.8	--	11.7	--	8.7	--	--
	7	26	D.F.	8.4	--	11.8	3.5	--	11.3	--	8.0	--	--
			Av.	8.6	-28.3[e]	12.0	3.6	-70.0[e]	11.5	-4.2	8.4	-30.0[e]	-27.0[e]
175	8	33-42	S.F.	12.0	--	14.7	6.2	--	14.4	--	11.5	--	--
	8	33-42	D.F.	13.6	--	15.6	7.7	--	16.0	--	13.6	--	--
			Av.	12.8	-15.8[e]	15.2	6.8	-55.3[e]	15.2	0.0	12.6	-17.1[e]	-17.1[e]
200	22	42	S.F.	14.6	--	16.7	8.3	--	17.0	--	14.2	--	--
	22	42	D.F.	14.7	--	16.8	8.3	--	17.2	--	14.5	--	--
			Av.	14.6	-13.1[e]	16.8	8.3	-50.6[e]	17.1	+1.8	14.4	-14.3[e]	-15.8[e]
275	11	69	S.F.	23.4	--	26.6	22.3	--	28.6	--	23.4	--	--
	11	69	D.F.	23.6	--	26.8	22.7	--	29.0	--	23.4	--	--
			Av.	23.5	-12.0[e]	26.7	22.5	-15.8[e]	28.8	+7.9[e]	23.4	-12.4[e]	-18.8[e]
350	10	90	S.F.	27.6	--	32.4	30.2	--	35.5	--	28.6	--	--
	10	90	D.F.	27.4	--	32.2	29.6	--	34.6	--	28.4	--	--
			Av.	27.5	-14.9[e]	32.3	29.9	-7.4[e]	35.0	+8.4[e]	28.5	-11.8[e]	-18.6[e]
			Grand av.	17.5	-15.0[e]	20.6	13.9	-32.5[e]	21.5	+4.4	17.6	-14.6[e]	-18.1[e]

[a] Arbitrarily based on modified ring compression results as reference.
[b] Difference between FPL and Weyerhaeuser tests based arbitrarily on FPL results.
[c] Tested on the H&D tester at 25 lb/sec.
[d] Tested on the Instron tester at 0.02 inch/min (FPL) and 0.08 inch/min (Weyerhaeuser).
[e] Difference is considered significant at the 0.05 level. Tests of significance were calculated using between sample variance. Natural logarithms of the data points were used to test for significance of the grand averages to reduce the effect of increasing variance with board series.

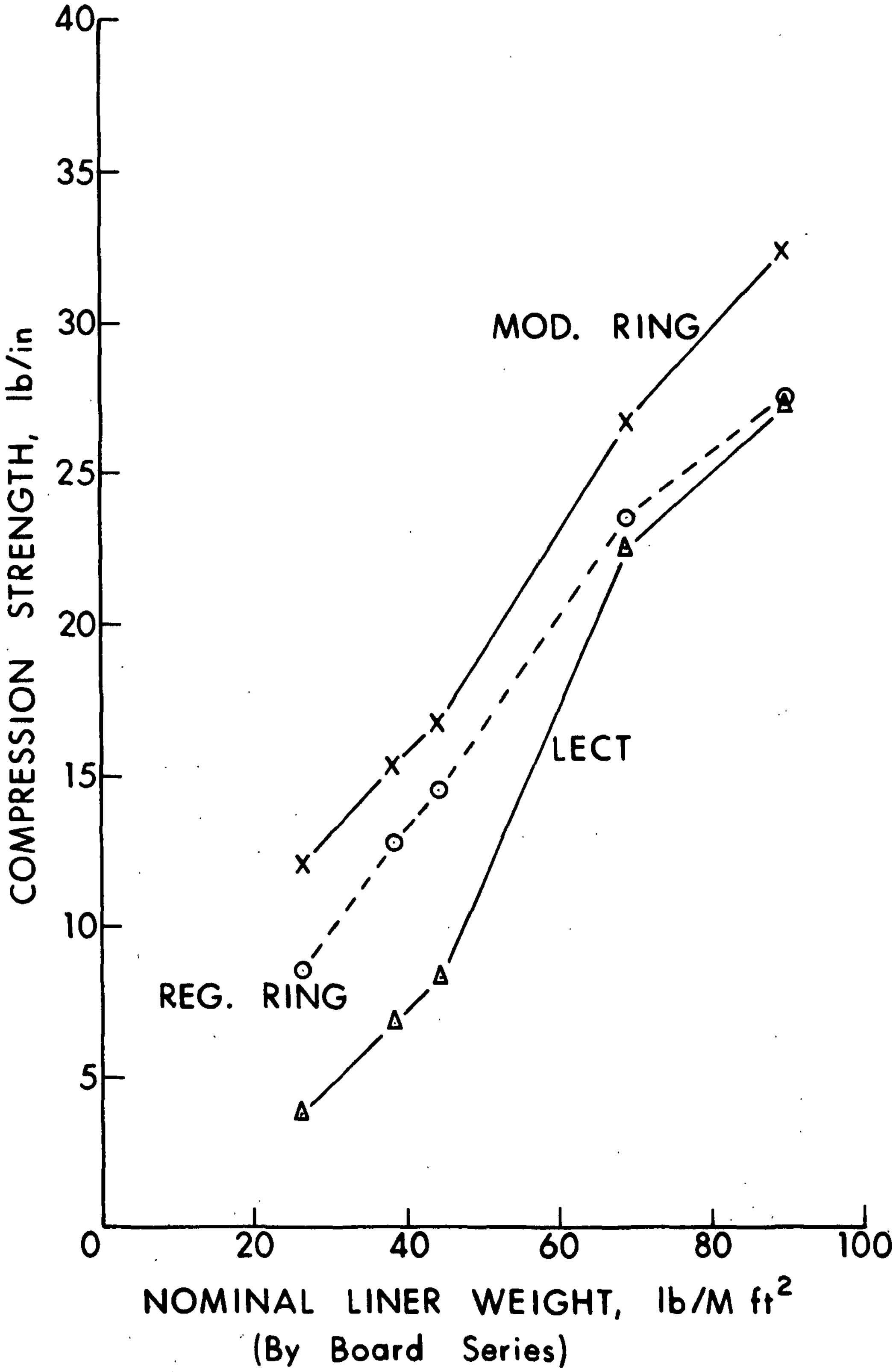

Figure 9. Comparison of Average Maximum Loads on Linerboard for Tests Carried out on H&D Compression Tester

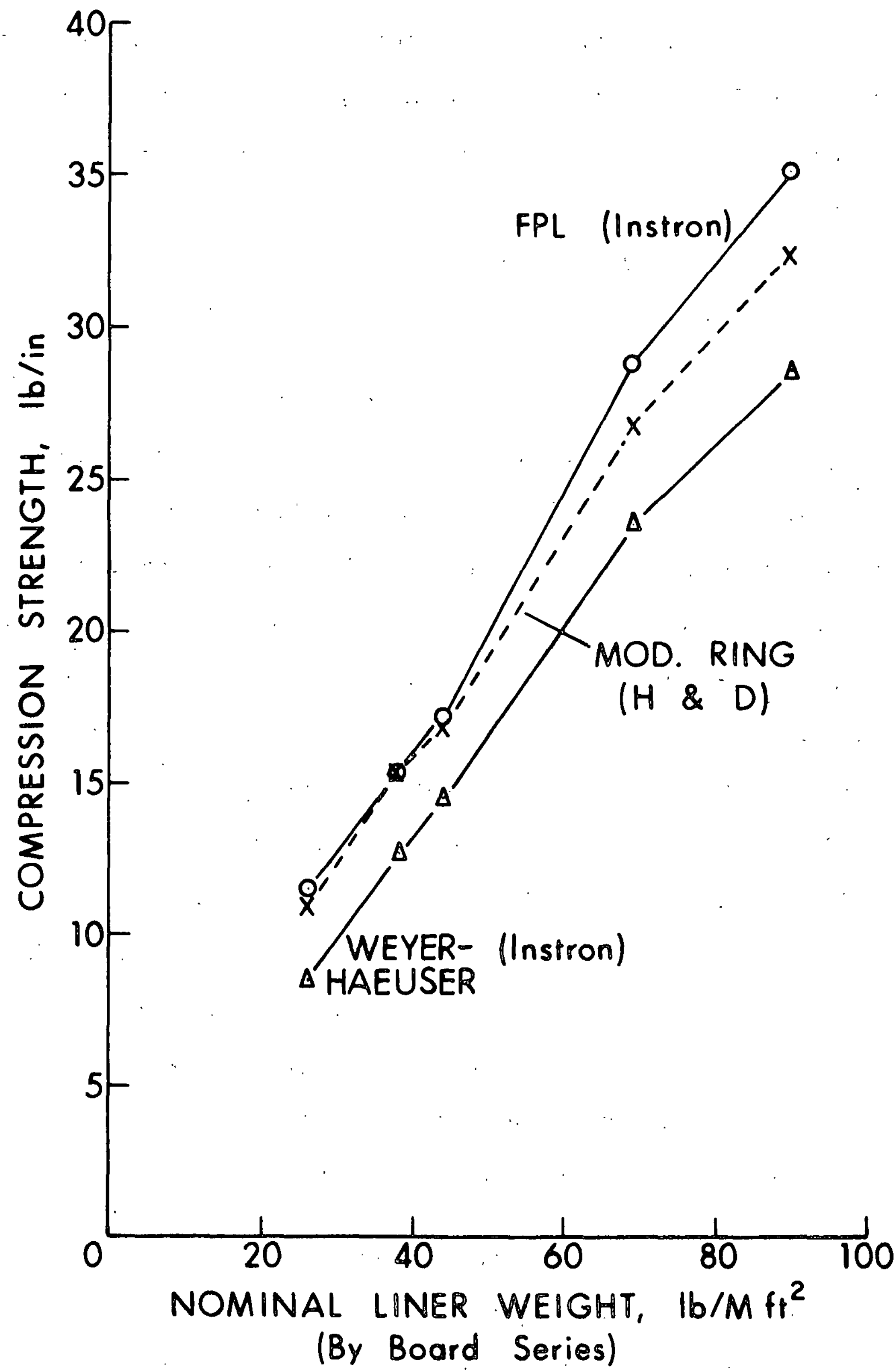

Figure 10. Comparison of Average Maximum Loads on Linerboard Obtained with FPL, Weyerhaeuser and Modified Ring Tests

series were only 7.4% below the modified ring results. These results are similar to those reported for an earlier comparison of the original CLT (with straightening bar) and the modified ring, although considerable improvement is noted in the higher weight liners (7). The very large differences at the low weights occur because the failure mode in the LECT is primarily one of buckling of the specimen and the groove in the upper holder appears to be too wide to provide support to the specimen.

Table I and Figure 10 show the FPL lateral support test results to be significantly higher than those obtained with the Weyerhaeuser lateral support test. The differences averaged 18.1% overall and were fairly consistent for the linerboards in the 175 to 350-lb series. However, for the linerboards in the 125-lb series, the average difference was 27.0%. The Weyerhaeuser test operates at a slightly higher strain rate than does the FPL test so the differences between the test results cannot be attributed to the difference in their strain rates since the higher rate would be expected to produce higher results. The FPL test fixture has a 0.001 inch relief on each side in the support area as discussed in the description of the test and it is possible that this small clearance introduces some frictional effects due to localized caliper variations. The differences between the maximum load results of the FPL and Weyerhaeuser tests prompted a further comparison of the two tests with regard to measurement of compressive modulus of elasticity and maximum strain at failure. The results of that study are described in another part of the report.

The results in Fig. 10 also show that the maximum loads obtained in the FPL and modified ring tests were approximately the same in the lower liner weight ranges. For the 69 and 90-lb linerboards, the FPL results were somewhat higher than the modified ring results, even though the modified ring test as used on the H&D operates at a much higher strain rate than the FPL test on the Instron.

The maximum load results at unequal strain rates on the medium samples are shown in Table II and depicted graphically in Fig. 11. They show the results of the medium tests to be very similar to those of the 26 lb linerboard as shown in Table I. The regular ring and Weyerhaeuser values are quite comparable and are 36.1% and 33.3% below the modified ring test values, respectively. The FPL test values are only 7.4% below the modified ring values, but this difference proves to be significant because of the large number of samples involved. The Concora Fluted Crush (CFC) test values are 7.4% above the modified ring values. However, this test is conducted on a specimen that is heated and dried in a Concora fluter immediately before testing and the test values are expected to be increased accordingly.

COMPARISON OF MAXIMUM LOAD RESULTS — NEARLY EQUAL STRAIN RATES

A limited number of sample lots (four samples from each combined board series and 10 samples of medium) was selected at random for use in evaluating the regular ring test, modified ring test, FPL test and Weyerhaeuser test at nearly equal strain rates. The FPL test on the Instron was run at 0.015 in./in./min and the Weyerhaeuser test was run at 0.023 in./in./min. As mentioned before, the discrete speed settings on the Instron would not allow exact equivalence of strain rates. However, these rates are considered close enough to allow a good comparison. A strain rate of 0.020 in./in./min. was selected for the ring tests on the Instron. This was the lowest operating rate available on that test machine. The slow operating rate resulted in some extremely long test times. Also, previous work

TABLE II

COMPARISON OF MAXIMUM LOAD LEVELS ON MEDIUM
(Unequal Strain Rates)

Average maximum load, lb

Board Series	No. of Medium Samples	Reg. Ring Comp.[c]	Diff., %[a]	Mod. Ring Comp.[c]	Concora Fluted Crush[d]	Diff., %[a]	FPL Comp.[e]	Diff., %[a]	Weyer-haeuser Comp.[e]	Diff., %[a]	Diff., %[b]
125	7	6.4	--	10.3	11.1	--	9.4	--	6.7	--	--
175	8	7.3	--	11.1	11.9	--	10.3	--	7.6	--	--
200	22	6.9	--	10.9	11.5	--	10.1	--	7.3	--	--
275	11	6.9	--	11.0	11.8	--	10.2	--	7.3	--	--
350	10	7.2	--	11.1	12.1	--	10.3	--	7.3	--	--
Grand av.		6.9	-36.1[f]	10.8	11.6	+7.4[f]	10.0	-7.4[f]	7.2	-33.3[f]	-28.0[f]

[a] Arbitrarily based on modified ring compression results as reference.
[b] Difference between FPL and Weyerhaeuser tests, arbitrarily based on FPL results.
[c] Tested on the H&D tester at 25 lb/sec.
[d] Tested on the H&D tester, tested immediately after fluting.
[e] Tested on the Instron tester at 0.02 inch/min (FPL) and 0.08 inch/min (Weyerhaeuser).
[f] Difference is considered significant at the 0.05 level. Tests of significance were calculated based on between sample variance.

has shown that ring compression strength values exhibit a definite fall-off below a strain rate of 0.1 in./in./min (7).

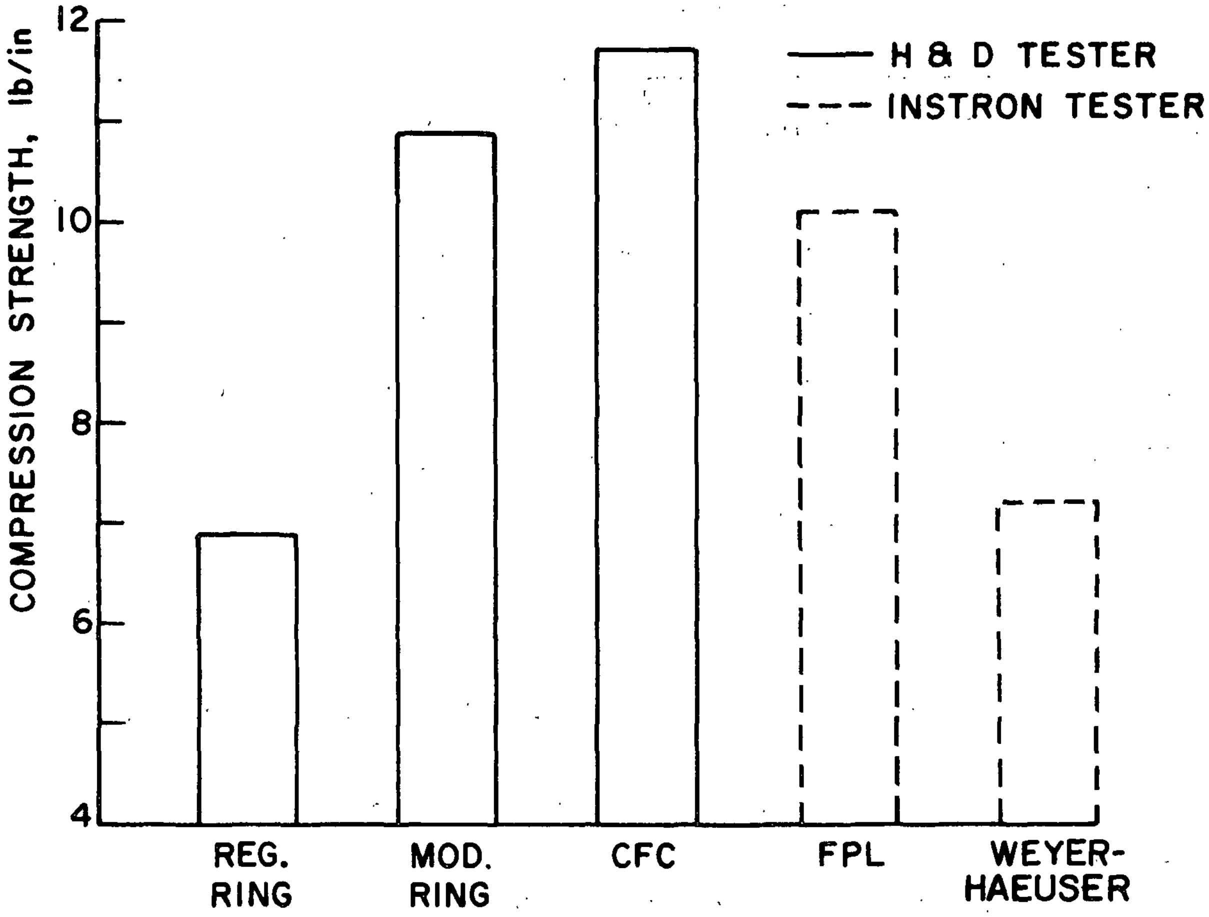

Figure 11. Comparison of Maximum Loads at Unequal Strain Rates on 26-lb Medium

A direct comparison of the results of the ring tests on the H&D and Instron machines appears in Table III. The regular ring values on the Instron averaged 18% lower than the H&D values for the liners and 15.3% lower than the H&D values for medium. The modified ring values were reduced 17% for liners and 23.9% for medium. Almost all of the reductions, when considered by individual board grade, were considered as significant.

TABLE III

COMPARISON OF REGULAR RING AND MODIFIED RING RESULTS
ON THE H&D AND INSTRON TESTERS

Maximum Load, lb/inch

Material[a]	Regular Ring H&D[b]	Regular Ring Instron[c]	Regular Ring Diff., %[d]	Modified Ring H&D[b]	Modified Ring Instron[c]	Modified Ring Diff., %
26-Lb liner	8.3	7.1	-15.1[e]	12.1	9.1	-24.7[e]
38-Lb liner	13.3	10.6	-20.3[e]	15.7	12.6	-19.5[e]
42-Lb liner	17.0	13.6	-19.5[e]	18.5	15.7	-14.9[e]
69-Lb liner	21.6	19.4	-10.5	26.0	22.0	-15.5[e]
90-Lb liner	28.2	21.6	-23.2[e]	31.3	26.4	-15.9
Liner average	17.7	14.5	-18.0[e]	20.7	17.2	-17.0[e]
26-Lb medium	6.8	5.8	-15.3[e]	10.9	8.3	-23.9[e]

[a] Averages based on 4 sample lots per grade weight for liners, 10 sample mediums.

[b] H&D tests run at 25 lb/sec.

[c] Instron tests run at 0.01 inch/min = 0.020 inch/inch/minute strain rate.

[d] Based on H&D results as reference.

[e] Difference is considered significant at the 0.05 level.

Table IV and Fig. 12 show the results of the regular ring, modified ring, FPL and Weyerhaeuser tests on linerboard at the nearly equivalent strain rates. The Weyerhaeuser and modified ring results are about equal in magnitude. The largest difference between the two tests occurred for the 26-lb basis weight series where the Weyerhaeuser values are shown to be a significant 12.1% lower than the modified ring values. The regular ring test values averaged 15.7% below the modified ring test values. The FPL results averaged 25% higher than the modified ring results and were 19.5% higher than the Weyerhaeuser lateral support results, again raising the possibility of frictional interference of the specimen with the sides of the FPL fixture in the region of the 0.001 inch clearance.

TABLE IV

COMPARISON OF LINERBOARD COMPRESSION RESULTS AT APPROXIMATELY EQUAL STRAIN RATES
(Instron Tester)

Maximum load, lb/inch

Nominal Liner Wt.,[a] lb/M ft²	Reg. Ring Comp.	Diff., %[b]	Mod. Ring Comp.	FPL Comp.	Diff., %[b]	Weyer-haeuser Comp.	Diff., %[b]	Diff., %[c]
26	7.1	-22.0[d]	9.1	11.0	+20.9[d]	8.0	-12.1[d]	-27.3[d]
38	10.6	-15.9[d]	12.6	15.2	+20.6[d]	12.5	-0.8	-17.8[d]
42	13.6	-13.4[d]	15.7	18.4	+17.2[d]	15.8	+0.6	-14.1[d]
69	19.4	-11.8[d]	22.0	28.6	+30.0[d]	23.2	+5.5[d]	-18.9[d]
90	21.6	-18.2	26.4	34.2	+29.5[d]	27.0	+2.3	-21.1[d]
Av.	14.5	-15.7[d]	17.2	21.5	+25.0[d]	17.3	+0.6	-19.5[d]

[a] Averages based on 4 sample lots per grade weight.
[b] Arbitrarily based on modified ring compression results as reference.
[c] Difference between FPL and Weyerhaeuser tests, arbitrarily based on FPL test.
[d] Difference is considered significant at the 0.05 level. Tests of significance were calculated using within sample variance. Natural logarithms of the data points were used to reduce the effect of increasing variance with increasing test values.

Note: Test rates were as follows:
FPL test — 0.02 inch/min, 0.015 inch/inch/min.
Weyerhaeuser test - 0.08 inch/min, 0.023 inch/inch/min.
Ring tests — 0.01 inch/min, 0.020 inch/inch/min.

The results of the tests on medium for the regular ring, modified ring, FPL and Weyerhaeuser test on the Instron are shown to be similar to the results of the tests on linerboard. Table V identifies the values by individual sample. The Weyerhaeuser test results average a significant 12.2% lower than the modified

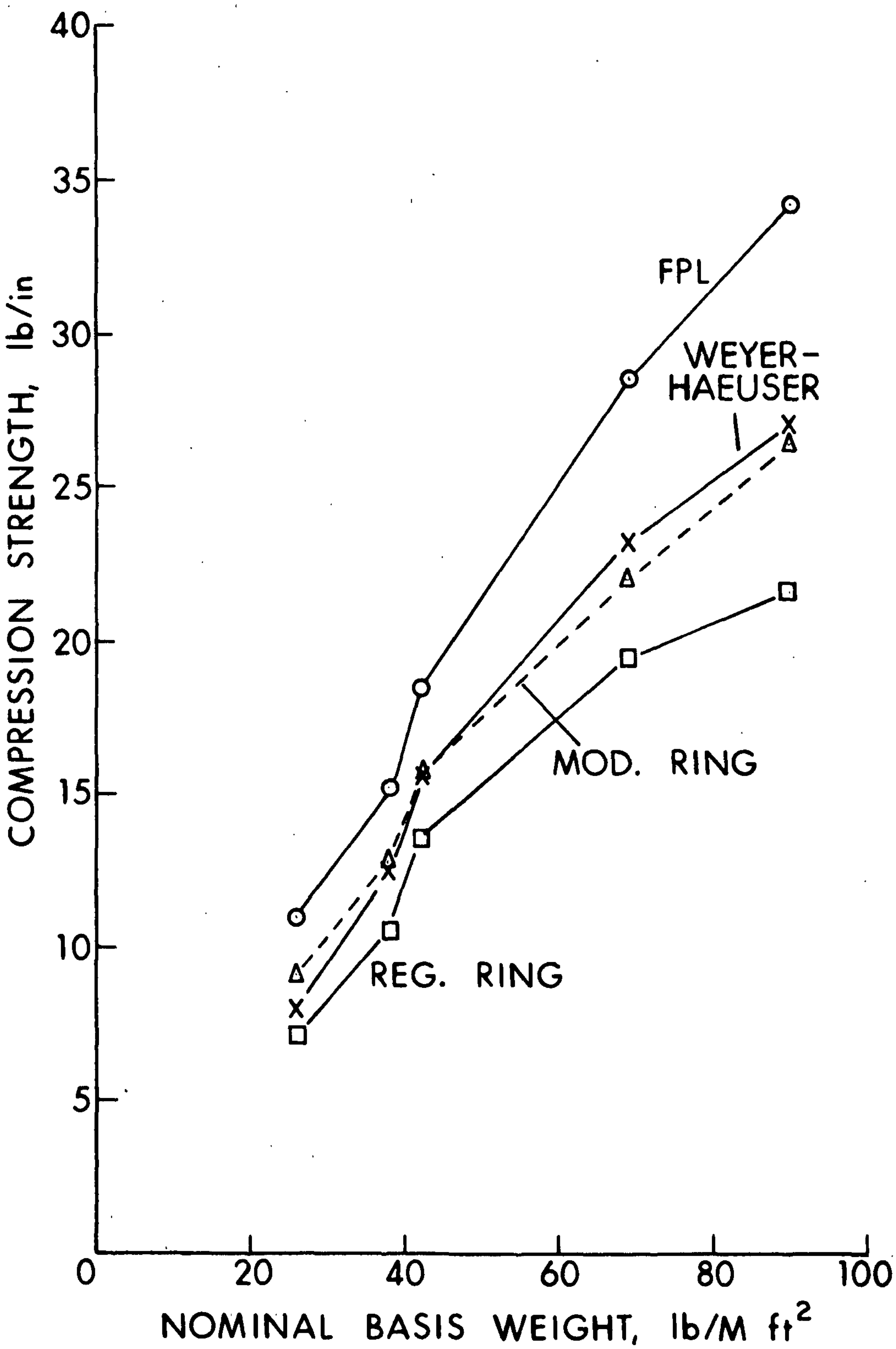

Figure 12. Comparison of Average Maximum Loads on Linerboard at Approximately Equal Strain Rates

ring results. This is similar to the results on 26-lb linerboard discussed earlier. The FPL results are 22% higher than the modified ring results, and this also agrees with the linerboard test results.

TABLE V

COMPARISON OF MEDIUM COMPRESSION RESULTS ON INSTRON TESTER
(Approximate equivalent strain rates)

Maximum load, lb/inch

Medium Sample No.	Reg. Ring Comp.	Diff., %[a]	Mod. Ring Comp.	FPL Comp.	Diff., %[a]	Weyer-haeuser Comp.	Diff., %[a]	Diff., %[b]
882	5.7	-29.6[c]	8.1	10.1	+24.7[c]	7.3	-9.9[c]	-27.7[c]
898	6.3	-31.5[c]	9.2	10.6	+15.2[c]	7.7	-16.3[c]	-27.4[c]
933	5.4	-31.6[c]	7.9	9.8	+24.1[c]	6.9	-12.7[c]	-29.6[c]
941	5.8	-28.4[c]	8.1	9.9	+22.2[c]	7.0	-13.6[c]	-29.3[c]
949	5.8	-23.7[c]	7.6	8.9	+17.1[c]	6.8	-10.5[c]	-23.6[c]
961	6.1	-30.7[c]	8.8	11.0	+25.0[c]	8.9	0.0	-19.1[c]
969	5.9	-36.6[c]	9.3	11.1	+19.4[c]	7.6	-18.3[c]	-31.5[c]
993	4.8	-35.1[c]	7.4	8.8	+18.9[c]	5.8	-21.6[c]	-34.1[c]
1045	5.4	-28.9[c]	7.6	9.7	+27.6[c]	6.2	-18.4[c]	-36.1[c]
1069	6.3	-25.9[c]	8.5	10.2	+20.0[c]	7.5	-11.8[c]	-26.5[c]
Av.	5.8	-29.3[c]	8.2	10.0	+22.0[c]	7.2	-12.2[c]	-28.0[c]

[a] Based arbitrarily on modified ring results as reference.
[b] Difference between FPL and Weyerhaeuser test, arbitrarily based on FPL results.
[c] Difference is considered significant at the 0.05 level. Tests of significance were calculated using within sample variance.

COMPARISON OF TEST VARIABILITY

It was decided to evaluate test variability by two slightly different approaches using the data generated by the tests run as designed (unequal strain rates). The coefficient of variation was calculated for each sample and these were tabulated (see appendix) and averaged to produce overall average coefficients of variation for linerboard and medium. For the second approach, a one way analysis of variance was calculated on all of the sample values (by board series and overall) and the within sample variances tabulated. In this case, a transformation of data points to natural logarithms was used to calculate the overall within sample variance for each test. This was done to eliminate the effects of increasing variance as test values increased with the higher board series.

The results of both approaches are shown in Table VI for linerboard and Table VII for medium.

For the linerboard, the modified ring test shows the lowest overall coefficient of variation, followed by the regular ring test, LECT, FPL and Weyerhaeuser tests in that order. The results are somewhat different for the medium, with the CFC exhibiting the lowest overall coefficient of variation, followed by the modified ring, FPL, regular ring and Weyerhaeuser tests. The regular ring, LECT and Weyerhaeuser tests show a tendency toward higher coefficients of variation at the lighter liner weights.

The overall within sample variance calculations based on the natural logarithms of the data points are in good agreement with the coefficient of variation values. The linerboard calculations based on the variance analysis show the modified ring test to be the least variable followed by the regular ring test, Weyerhaeuser, LECT and FPL tests. Note that the Weyerhaeuser test is shown to be better than the LECT and FPL tests using this procedure. It should be noted that all of these variance values are considered significantly different from each other. The FPL within sample variances for the individual board series seem to be considerably higher than those of the other tests at the higher liner weights.

TABLE VI

SUMMARY OF LINERBOARD EDGEWISE COMPRESSION TEST VARIABILITY (CROSS DIRECTION)

Board Series and Liner[a]	Within Sample Variance, lb					Coefficient of Variation, %				
	Reg. Ring Comp.	Mod. Ring Comp.	Liner Edge Crush (LECT)	FPL Comp.	Weyer-haeuser Comp.	Reg. Ring Comp.	Mod. Ring Comp.	Liner Edge Crush (LECT)	FPL Comp.	Weyer-haeuser Comp.
125-lb Single face	0.3504	0.4303	0.1226	1.1228	1.1048	6.7	5.4	8.3	8.7	11.5
125-lb Double face	0.4519	0.6093	0.0935	0.8377	1.1173	7.9	6.2	8.1	7.8	12.9
Average	0.4012	0.5198	0.1080	0.9802	1.1110	7.3	5.8	8.2	8.2	12.2
175-lb Single face	0.4931	0.7177	0.2267	1.4185	1.5538	5.8	5.6	7.6	7.9	10.3
175-lb Double face	0.5807	0.5413	0.3810	1.6024	1.1470	5.7	4.7	7.8	7.8	7.9
Average	0.5368	0.6295	0.3038	1.5104	1.3504	5.8	5.2	7.7	7.8	9.1
200-lb Single face	0.6657	0.9278	0.4818	2.1483	1.8917	5.5	5.6	8.1	8.4	8.9
200-lb Double face	0.7204	0.7053	0.4645	1.6513	1.2282	5.6	4.9	7.8	7.3	7.4
Average	0.6930	0.8166	0.4732	1.8998	1.5600	5.6	5.2	8.0	7.8	8.2
275-lb Single face	1.2924	1.4186	1.5590	6.4167	2.9727	4.7	4.3	5.4	8.4	7.1
275-lb Double face	1.1122	1.3024	1.5419	5.5619	3.6364	4.5	4.1	5.2	7.8	7.5
Average	1.2023	1.3605	1.5504	5.9893	3.3046	4.6	4.2	5.3	8.1	7.3
350-lb Single face	1.5660	2.1382	2.4118	9.2464	5.4361	4.4	4.4	5.0	8.6	7.2
350-lb Double face	1.2132	2.0049	2.7181	8.3604	5.4361	4.0	4.3	5.3	8.1	7.4
Average	1.3896	2.0716	2.5650	8.8034	5.4361	4.2	4.4	5.2	8.4	7.3
Grand average	0.7801	0.9814	0.8845	3.3703	2.2560	5.4	4.9	7.0	8.0	8.5
Grand average (Ln)[b]	0.0033	0.0028	0.0054	0.0072	0.0049					

[a]Results are the average of 58 liner samples (each face), evaluated with 10 determinations.
[b]Grand average within sample variance calculated using a transformation of all data points to natural logarithms to reduce the effect of increasing variance with higher test readings.
All grand average values of within sample variance calculated using natural logarithms are considered significantly different from each other at the 0.05 level.

TABLE VII

SUMMARY OF MEDIUM EDGEWISE COMPRESSION TEST VARIABILITY

	Within Sample Variance, lb					Coefficient of Variation, %				
Board Series[a]	Reg. Ring Comp.	Mod. Ring Comp.	Concora Fluted Crush (CFC)	FPL Comp.	Weyer-haeuser Comp.	Reg. Ring Comp.	Mod. Ring Comp.	Concora Fluted Crush (CFC)	FPL Comp.	Weyer-haeuser Comp.
Medium from 125 lb	0.2312	0.2129	0.2233	0.3807	0.4720	7.4	4.4	3.9	6.4	9.8
Medium from 175 lb	0.2173	0.3199	0.4121	0.4061	0.2857	6.2	5.0	5.2	6.1	6.6
Medium from 200 lb	0.2035	0.3503	0.3017	0.4803	0.3598	6.4	5.2	4.7	6.7	8.1
Medium from 275 lb	0.2615	0.3933	0.3420	0.6329	0.4611	7.2	5.6	4.8	6.9	9.2
Medium from 350 lb	0.2327	0.4099	0.2976	0.4896	0.5055	6.7	5.7	4.4	6.6	9.2
Grand average	0.2050	0.3189	0.2872	0.4474	0.3715	6.7	5.2	4.7	6.6	8.5
Grand average (Ln)[b]	0.0049[c]	0.0030	0.0023	0.0051[c]	0.0084					

[a]Results are the average of 58 medium samples, each evaluated with 10 determinations.

[b]Grand average within sample variance calculated using a transformation of all data points to natural logarithms to reduce the effect of increasing variance with higher test readings.

[c]Grand average values of within sample variance calculated using natural logarithms are considered significantly different at the 0.05 level except for those marked as (c).

In the medium results, the CFC test within sample variance proved to be lowest, again agreeing with the coefficient of variation values. The Weyerhaeuser test had the highest within sample variance, while the regular ring and FPL test variances were not significantly different from each other.

In analyzing these results, it must be remembered that the Weyerhaeuser test specimen width is only about 0.79 inch and the FPL test specimen width is only 1.00 inch compared to the 6-inch width of the ring tests, LECT and CFC. This could produce higher variability in the FPL and Weyerhaeuser tests since a much smaller specimen is tested and there is less "averaging" of the material properties. The higher variability of the FPL test at the higher liner weights (calipers) again lends credence to the theory that some frictional interference might be present since the thicker calipers would tend to compress more in the clamp area than would the thinner calipers and, therefore, have more interference with the sides of the fixture and result in larger variations in test results.

Graphical presentations of both the coefficient of variation and within sample variance values for linerboard and medium are shown in Fig. 13 and 14.

COMPARISON OF MODULUS AND MAXIMUM STRAIN FOR LATERAL SUPPORT TESTS

As mentioned previously, the large differences between the maximum load values of the FPL and Weyerhaeuser tests prompted an additional investigation into the compression moduli and maximum strain at failure values for the two tests. For this purpose, 20 liner and 10 medium samples were evaluated using 5 tests per sample. The results are summarized in Table VIII and illustrated in Fig. 15.

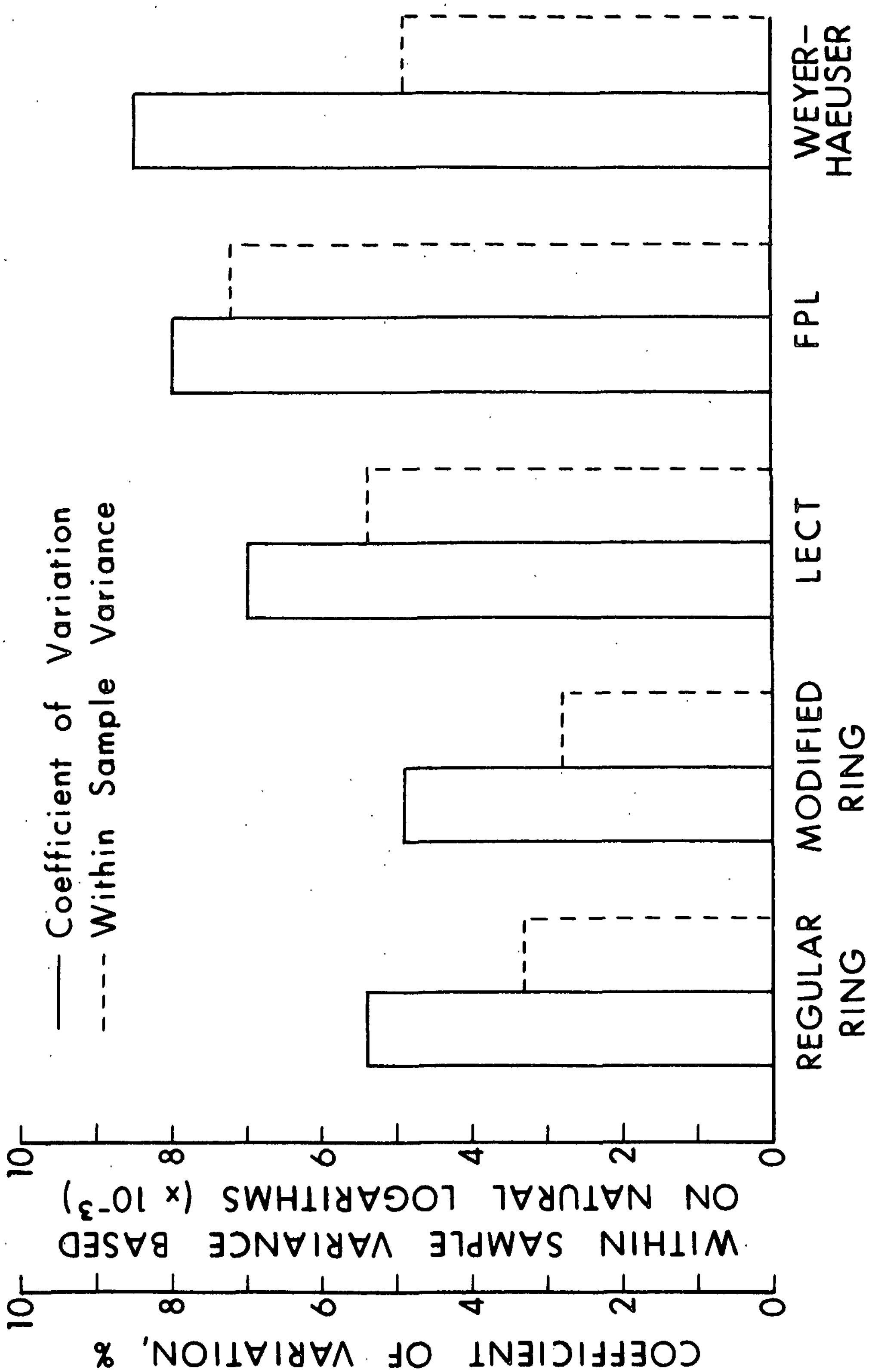

Figure 13. Overall Test Variability on Liners as Measured by Within Sample Variance (Natural Logarithms) and Coefficient of Variation

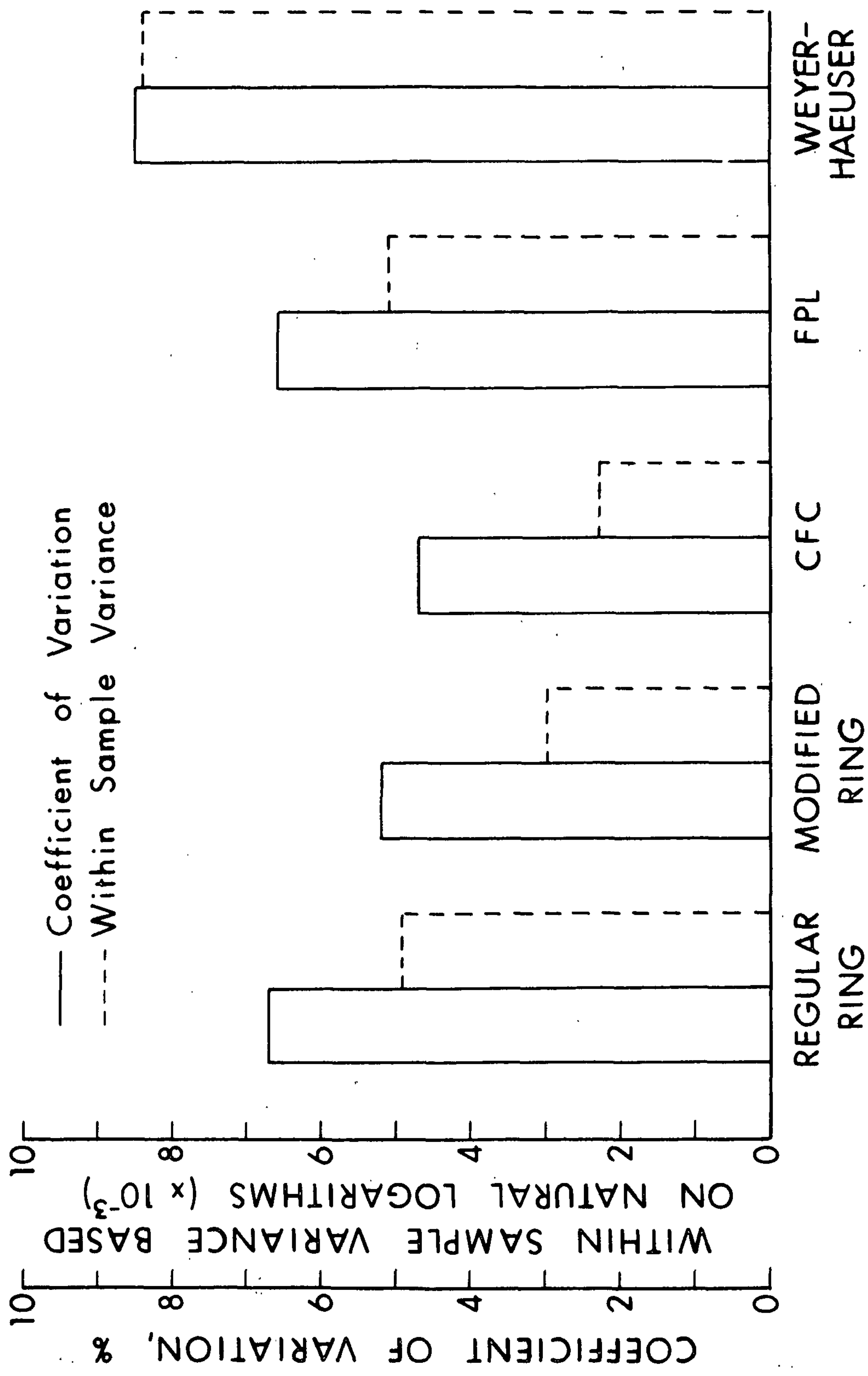

Figure 14. Overall Test Variability on Medium as Measured by Within Sample Variance (Natural Logarithms) and Coefficient of Variation

TABLE VIII

COMPARISON OF CROSS DIRECTION MODULUS AND MAXIMUM STRAIN

Material	No. of Samples	Average C.D. Modulus, psi[b] FPL	Weyer-haeuser	Diff., %[a]	Max. Strain, %[b] FPL	Weyer-haeuser	Diff., %[a]
26-Lb medium	10	254,000	176,000	-30.9	0.81	0.53	-35.4
26-Lb liner	4	302,000	284,000	-6.0	0.74	0.44	-40.9
38-Lb liner	4	319,000	256,000	-19.9	0.75	0.55	-27.0
42-Lb liner	4	310,000	293,000	-5.6	0.79	0.58	-27.0
69-Lb liner	4	428,000	285,000	-33.5	0.73	0.54	-25.1
90-Lb liner	4	305,000	226,000	-25.9	0.92	0.62	-32.8
Composite av.	--	307,000	238,000	-22.5	0.79	0.54	-31.6

[a]Based arbitrarily on FPL results as reference.
[b]Corrected for instrumental strain.

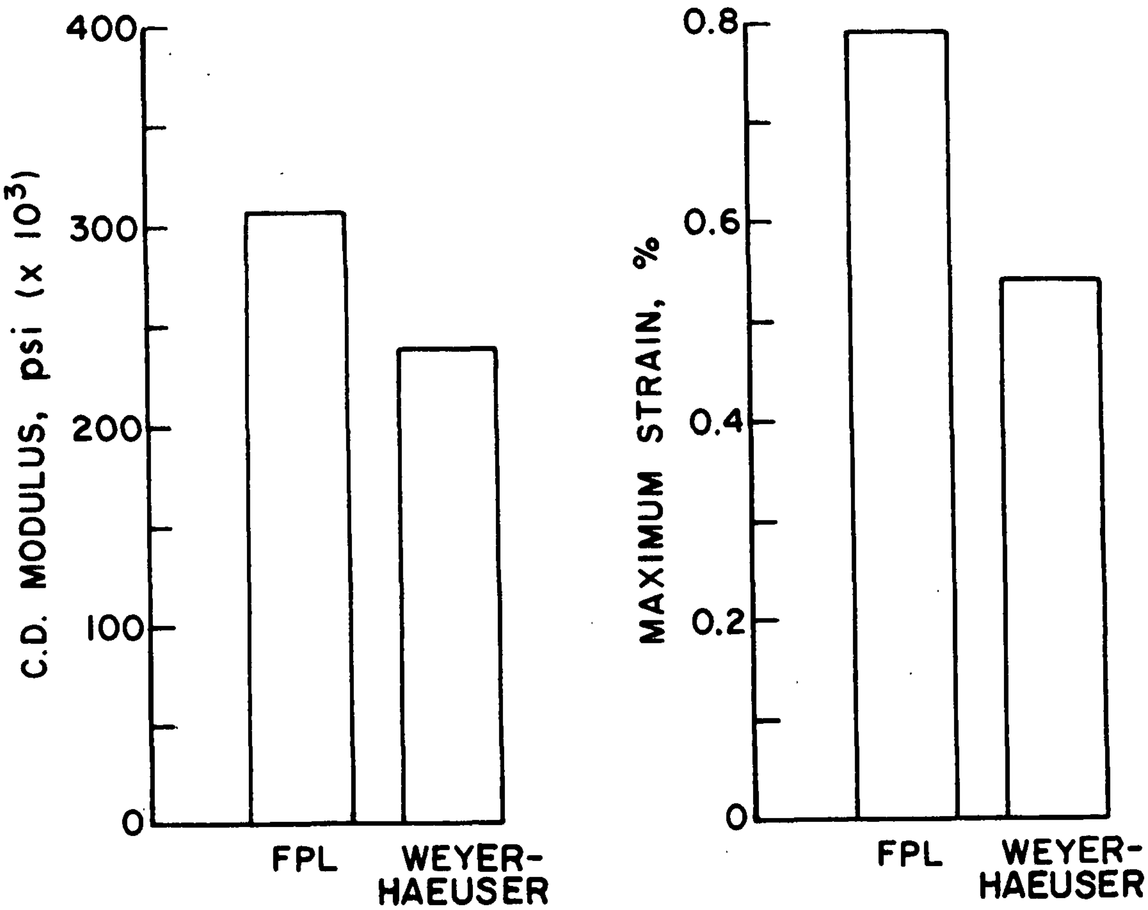

Figure 15. Comparison C.D. Modulus and Maximum Strain for the Lateral Support Tests

The differences between the tests on maximum load rates carried through to both the cross direction compression modulus and maximum strain at failure values. The results indicate that the cross direction modulus values obtained with the Weyerhaeuser test were 22.5% lower than the FPL results on the average. Similarly, the maximum strains obtained in the Weyerhaeuser test averaged 31.6% lower than the strains obtained in the FPL test. These differences are substantial and, as yet, unexplained. A more thorough study of these differences along with a comparison of compression moduli with tensile moduli for the two tests is presently being made as part of another project.

CORRELATION OF LATERAL SUPPORT TESTS WITH THE OTHER TESTS

The maximum load test values of the two lateral support tests (FPL and Weyerhaeuser) were correlated within a board series and overall to each other and to the other test values because of their different approach to measuring the edgewise compression strength. Table IX summarizes the results obtained in terms of ($\underline{R}^2$) - the square of the multiple correlation coefficient. This can also be called "the proportion of variance explained by the regression." The individual plots of the data points are shown in Fig. 16 through 29.

As seen in Table IX, all of the overall correlations are high because of the large number of data points used. Both the FPL and Weyerhaeuser tests correlated best with the modified ring and with each other.

TABLE IX

CORRELATION OF FPL AND WEYERHAEUSER TESTS WITH OTHERS

Correlation of	Correlation with		Proportion of Explained Variable ($\underline{R}^2$)[a] 125-Lb Series ($\underline{N}$=7)	175-Lb Series ($\underline{N}$=8)	200-Lb Series ($\underline{N}$=22)	275-Lb Series ($\underline{N}$=11)	350-Lb Series ($\underline{N}$=10)	Composite ($\underline{N}$=58)
FPL	Regular ring	liner	0.92	0.79	0.76	0.71	0.35	0.96
		medium	--	--	--	--	--	0.56
FPL	Modified ring	liner	0.68	0.77	0.87	0.85	0.70	0.99
		medium	--	--	--	--	--	0.71
FPL	LECT	liner	0.83	0.72	0.50	0.69	0.61	0.98
	CFC	medium	--	--	--	--	--	0.60
Weyerhaeuser	Regular ring	liner	0.85	0.70	0.85	0.71	0.35	0.97
		medium	--	--	--	--	--	0.61
Weyerhaeuser	Modified ring	liner	0.49	0.61	0.89	0.85	0.93	0.99
		medium	--	--	--	--	--	0.61
Weyerhaeuser	LECT	liner	0.93	0.67	0.42	0.76	0.78	0.96
	CFC	medium	--	--	--	--	--	0.49
Weyerhaeuser	FPL	liner	0.90	0.79	0.86	0.95	0.79	0.99
		medium	--	--	--	--	--	0.71

[a] Regression Form $\underline{y} = \underline{b}_0 + \underline{b}_1 \underline{X}$

where $\underline{X}$ = average of single-face and double-face liner results or the medium result for a given test.

Note: The underline indicates that the regression was significant at the 0.05 level.

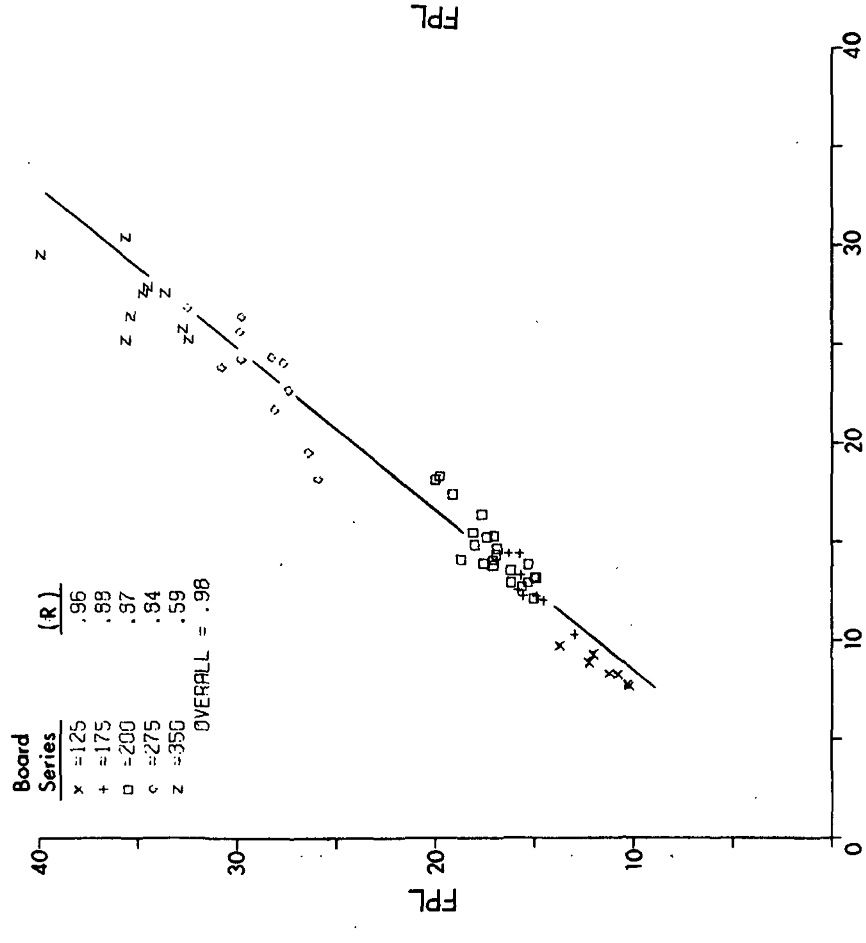

Figure 16. Correlation of FPL Test with Regular Ring Test on Liners

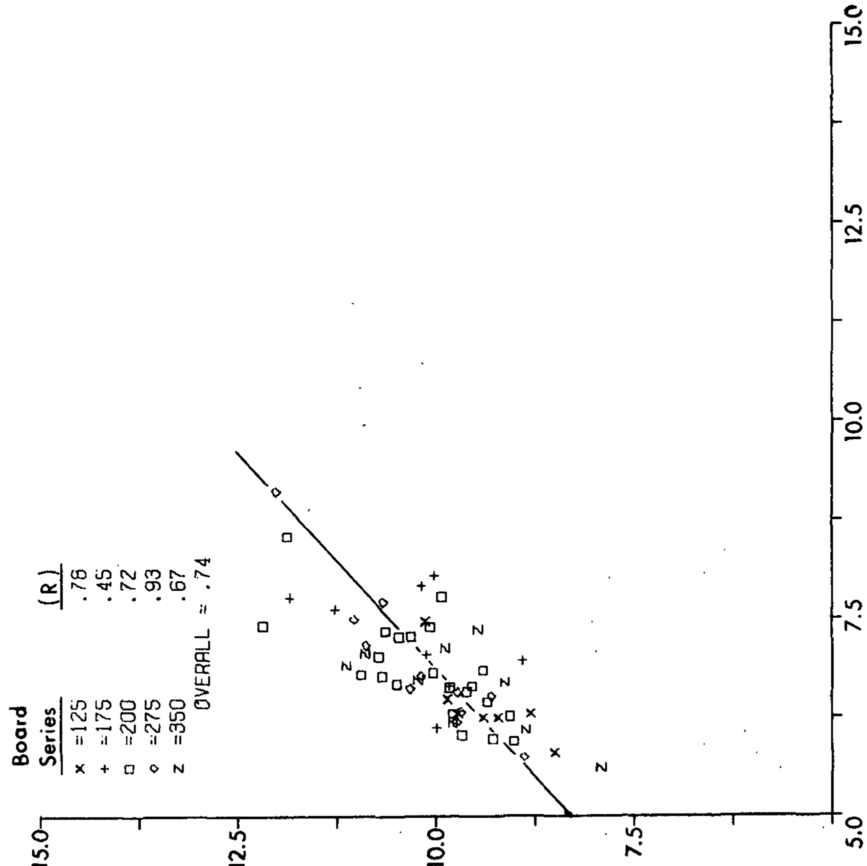

Figure 17. Correlation of FPL Test with Regular Ring Test on Medium

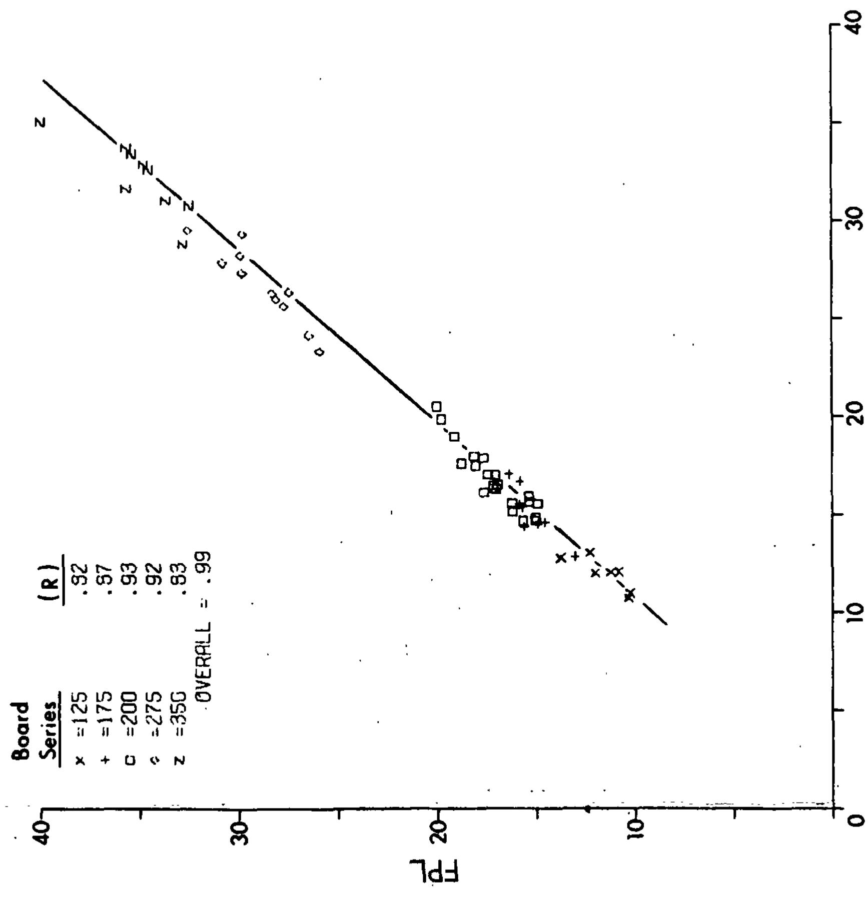

Figure 18. Correlation of FPL Test with Modified Ring Test on Liners

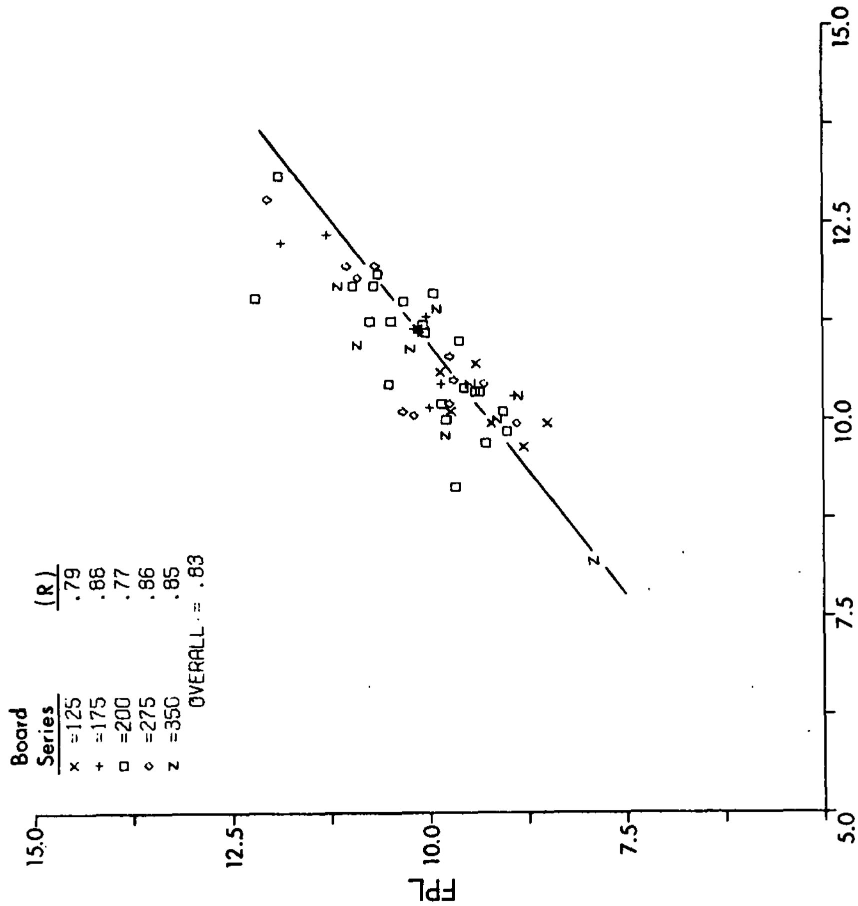

Figure 19. Correlation of FPL Test with Modified Ring Test on Medium

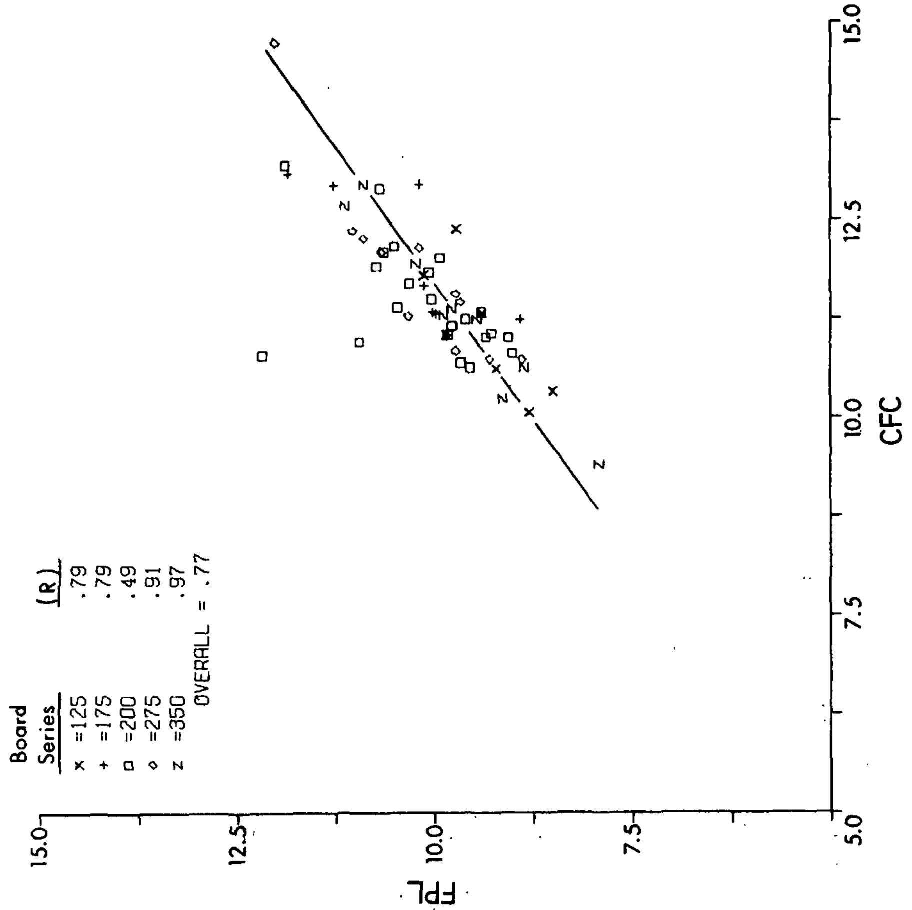

Figure 21. Correlation of FPL Test with CFC Test on Medium

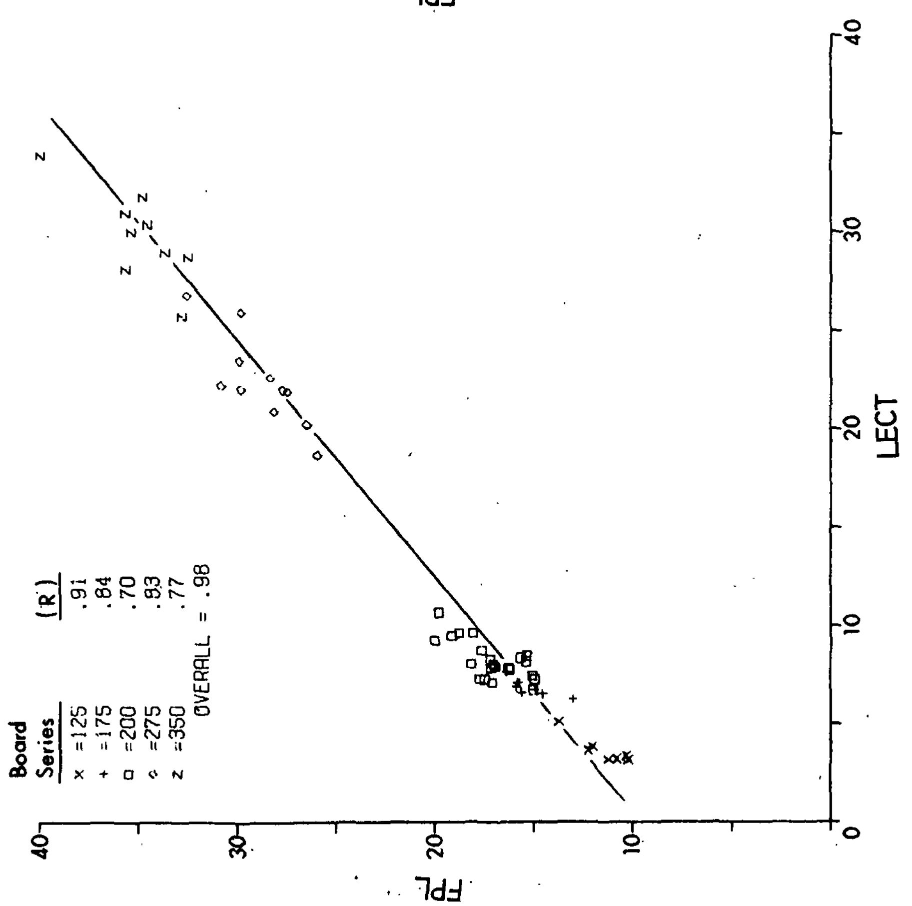

Figure 20. Correlation of FPL Test with LECT Test on Liners

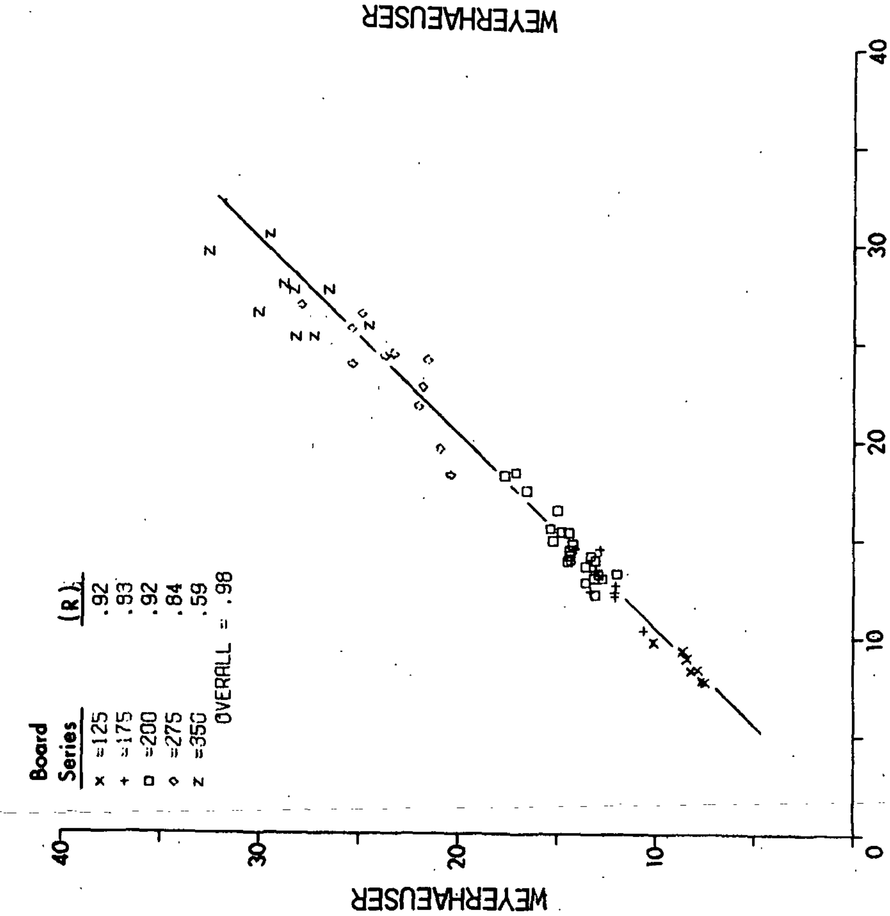

Figure 22. Correlation of Weyerhaeuser Test with Regular Ring Test on Liners

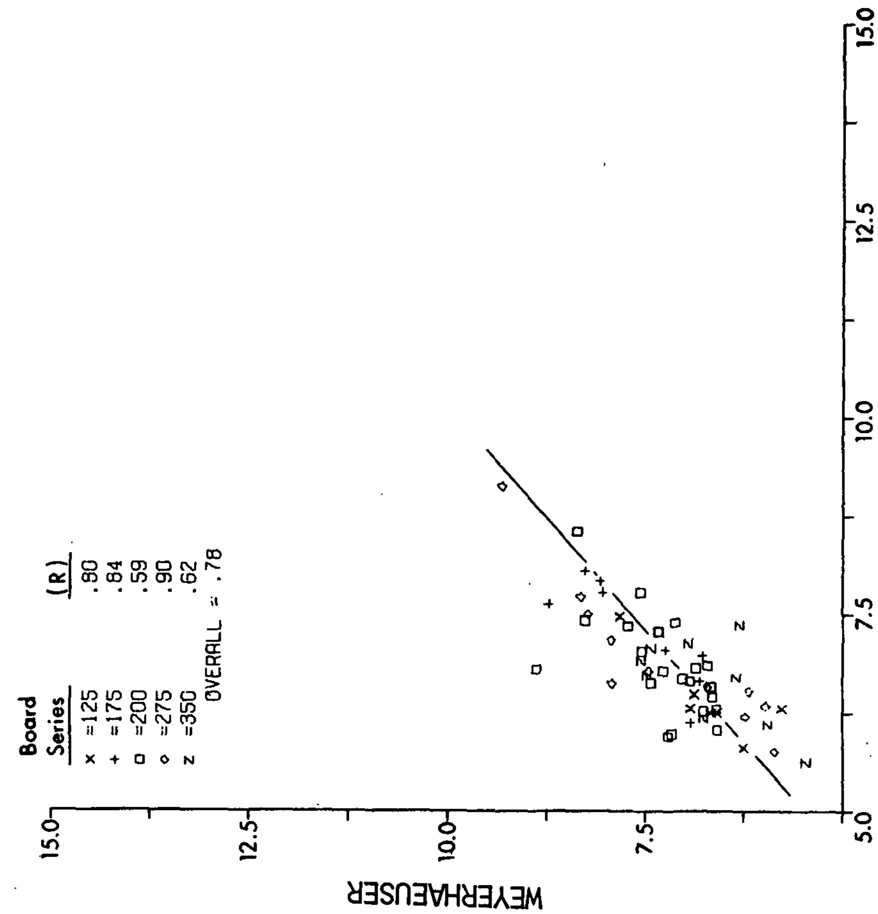

Figure 23. Correlation of Weyerhaeuser Test with Regular Ring Test on Medium

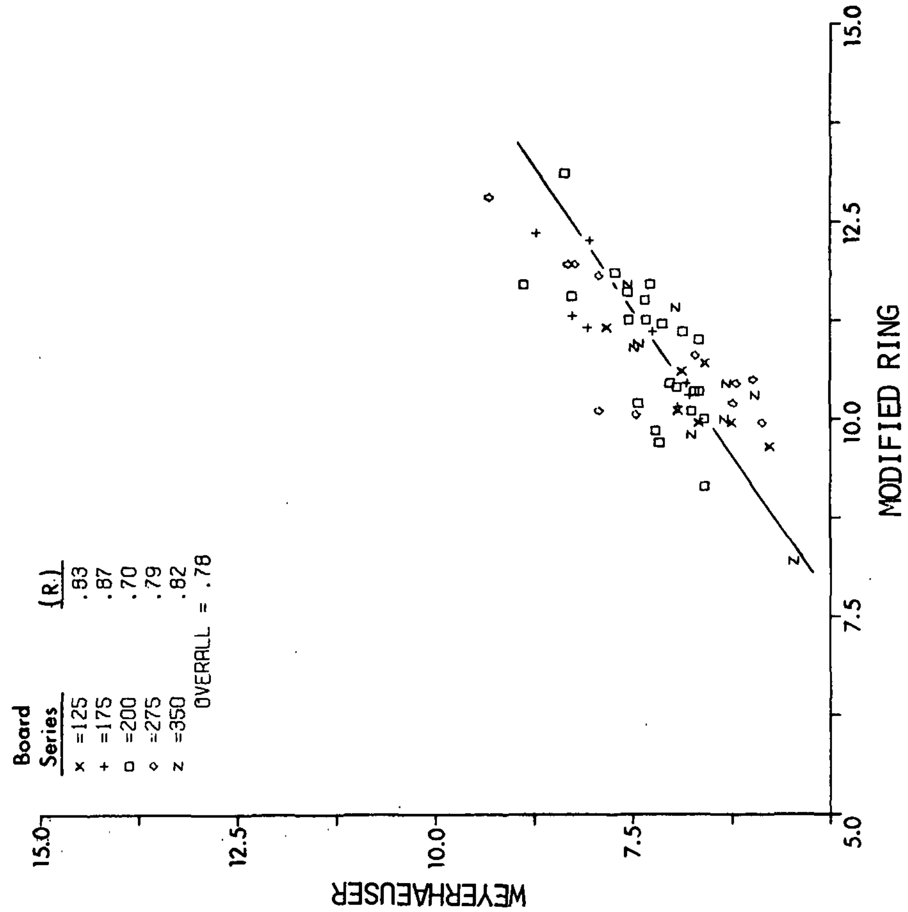

Figure 25. Correlation of Weyerhaeuser Test with Modified Ring Test on Medium

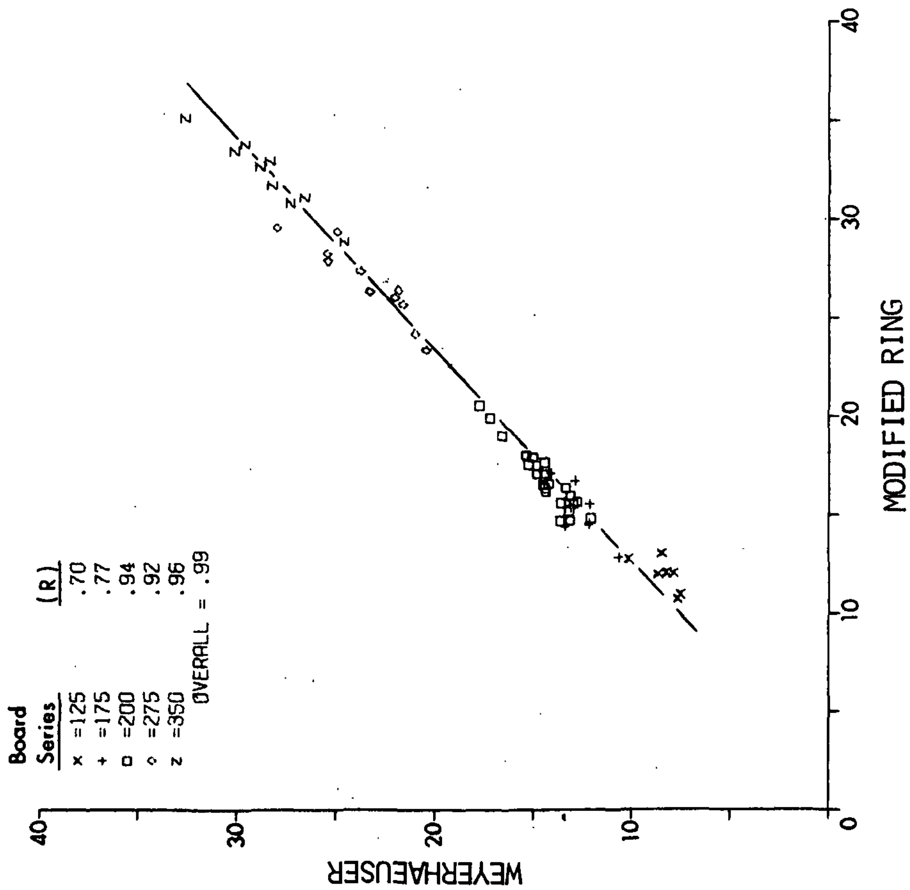

Figure 24. Correlation of Weyerhaeuser Test with Modified Ring Test on Liners

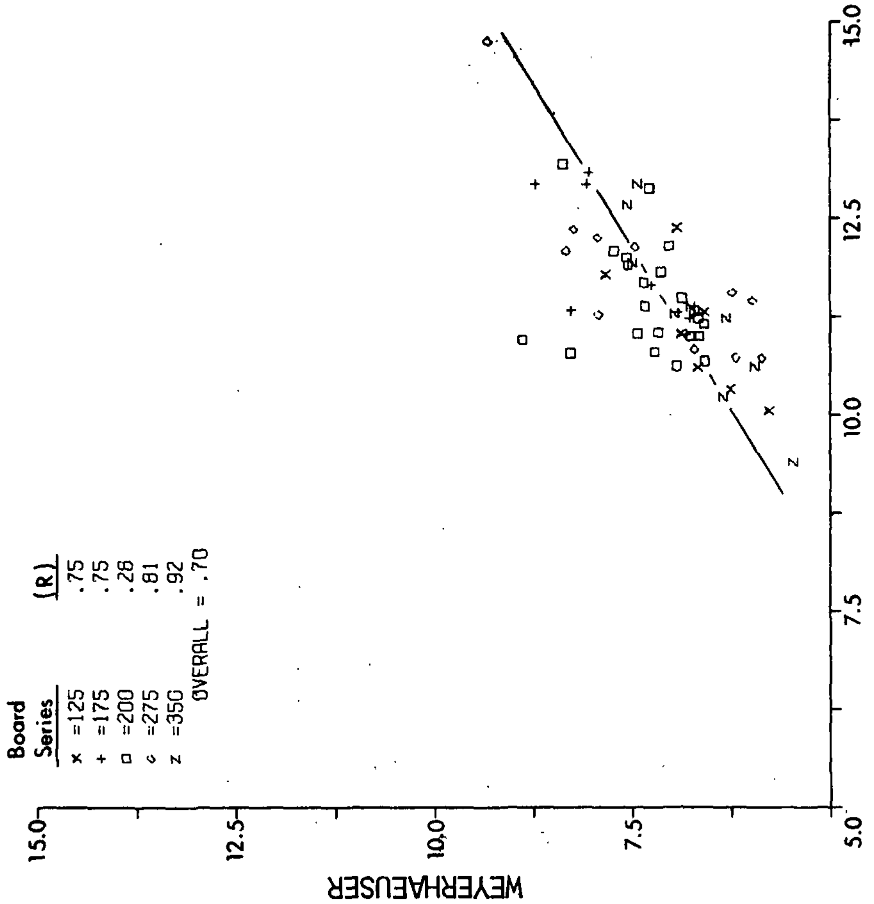

Figure 27. Correlation of Weyerhaeuser Test with CFC Test on Medium

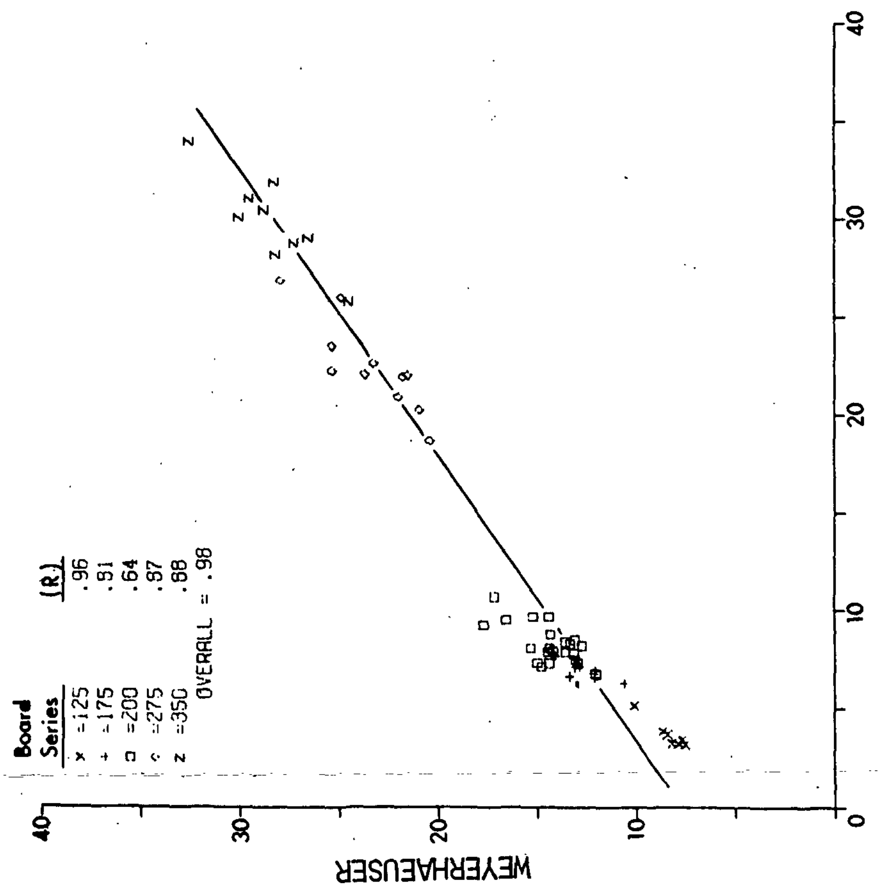

Figure 26. Correlation of Weyerhaeuser Test with LECT Test on Liners

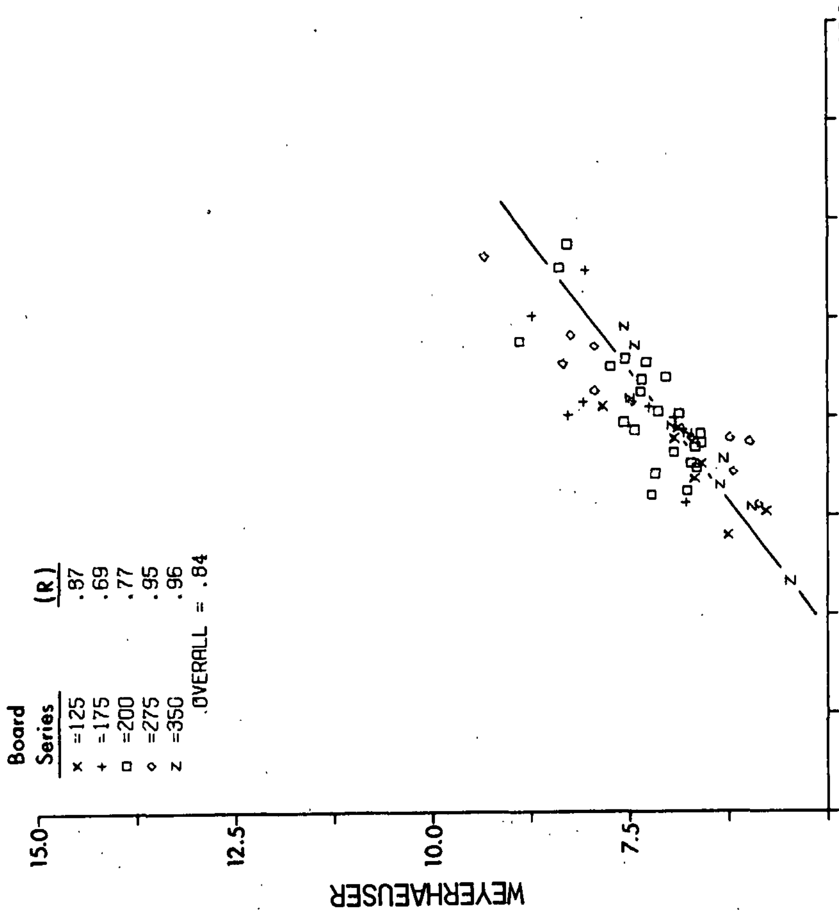

Figure 29. Correlation of Weyerhaeuser Test with FPL Test on Medium

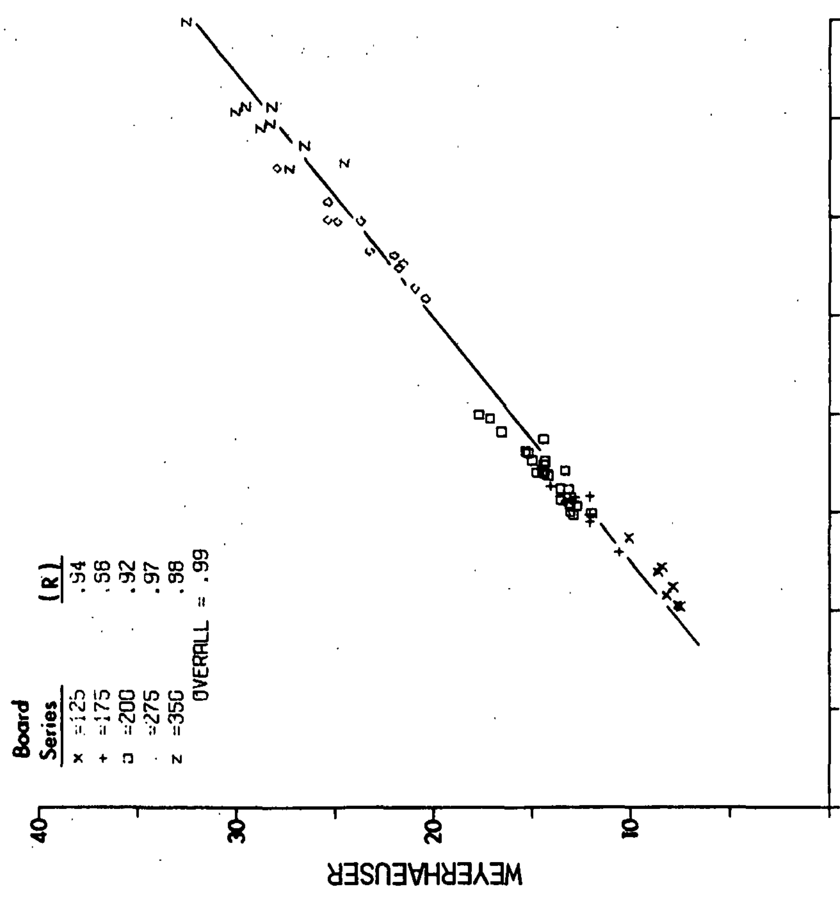

Figure 28. Correlation of Weyerhaeuser Test with FPL Test on Liners

In considering the correlations within the individual board series, the FPL test correlated well with the modified ring test through all of the series, but correlated better with the regular ring and LECT tests in the lighter weight liner groups. The Weyerhaeuser test correlated with the regular ring test about as well as did the FPL test. In correlation with the modified ring test, however, the Weyerhaeuser test did better in the heavier weight liner series than it did in the lighter weight series.

CORRELATION WITH COMBINED BOARD EDGEWISE COMPRESSION

The results for each component test were correlated with the combined board edgewise compression test (short column) results. The analysis was carried out using the following regression form:

$$y = b_0 + b_1 X_l + b_2 X_m$$

where

y = combined board edgewise compression

X_l = average of single and double-face liner results for a given test

X_m = medium result for the given test

b_0, b_1 and b_2 = regression constants

The correlations were carried out separately for each board series and on the composite results over all series. Table X summarizes the results obtained in terms of the multiple correlation coefficient (R).

No significant correlations were obtained for either the 125- or 175-lb series samples in part because the number of samples (N=7 and 8, respectively) was quite low. On the other hand, all tests showed good correlation overall because of the large number of samples spread over the range of board weights.

TABLE X

CORRELATION OF COMPONENT TESTS WITH COMBINED BOARD EDGEWISE COMPRESSION

Component Test		Multiple Correlation Coefficient (R)					
Liner	Medium	125-Lb Series (N=7)	175-Lb Series (N=8)	200-Lb Series (N=22)	275-Lb Series (N=11)	350-Lb Series (N=10)	Composite (N=58)
Reg. ring	Reg. ring	0.77	0.69	<u>0.88</u>	<u>0.89</u>	<u>0.86</u>	<u>0.98</u>
Mod. ring	Mod. ring	0.50	0.71	<u>0.84</u>	<u>0.91</u>	<u>0.96</u>	<u>0.98</u>
LECT	CFC	0.85	0.72	0.44	<u>0.89</u>	<u>0.97</u>	<u>0.97</u>
FPL	FPL	0.72	0.71	<u>0.78</u>	<u>0.83</u>	<u>0.97</u>	<u>0.98</u>
Weyerhaeuser	Weyerhaeuser	0.88	0.71	<u>0.79</u>	<u>0.87</u>	<u>0.97</u>	<u>0.98</u>

[a] Regression form: $y = b_0 + b_1 X_l + b_2 X_m$

when y = combined board edgewise compression
X_l = average of single and double-face liner results for the given test
X_m = medium result for the given test

Note: The underline indicates that the multiple regression was significant at the 0.05 level.

Considering the within grade results for all series, it appears that no one type of test correlates markedly better with the combined board results than any other test. In general, it appears that the "quality control" tests such as the regular ring and LECT/CFC combination correlated about as well as any of the tests. The LECT/CFC combination gave somewhat higher coefficients on the 125, 175 and 350-lb series samples than the regular ring. However, on the 200-lb series samples the LECT/CFC combination gave a coefficient of 0.44 which was much lower than the 0.88 coefficient obtained with the regular ring. A limited inspection of the results suggests that the low correlation might be due to caliper differences between the various 42-lb liner samples in this series.

After the regressions were made, the regression constants $\underline{b}_0$, $\underline{b}_1$ and $\underline{b}_2$ were used to calculate a value of combined board edgewise compression for each sample point. Each calculated value was then compared to the actual value and a series of graphs were made depicting the results. Figures 29 through 33 show the actual combined board edgewise compression values _versus_ the calculated combined board edgewise compression values for the regular ring test, modified ring test, LECT/CFC combination, FPL test and Weyerhaeuser test, respectively. The equation used to generate the calculated values is also included on the figures. As expected from the high $\underline{R}$ values, most points lie near the theoretical $\underline{R}$ = 1.00 line for all five tests.

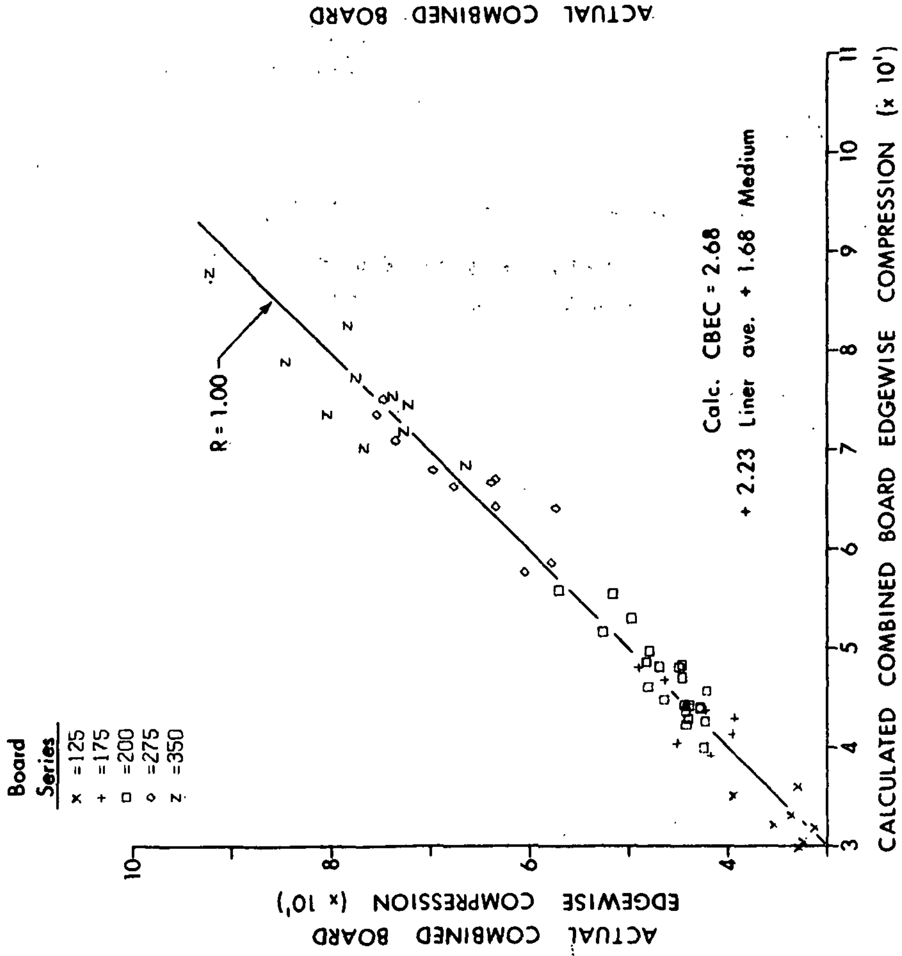

Figure 29. Calculated Versus Actual Combined Board Edgewise Compression for Regular Ring Crush Test

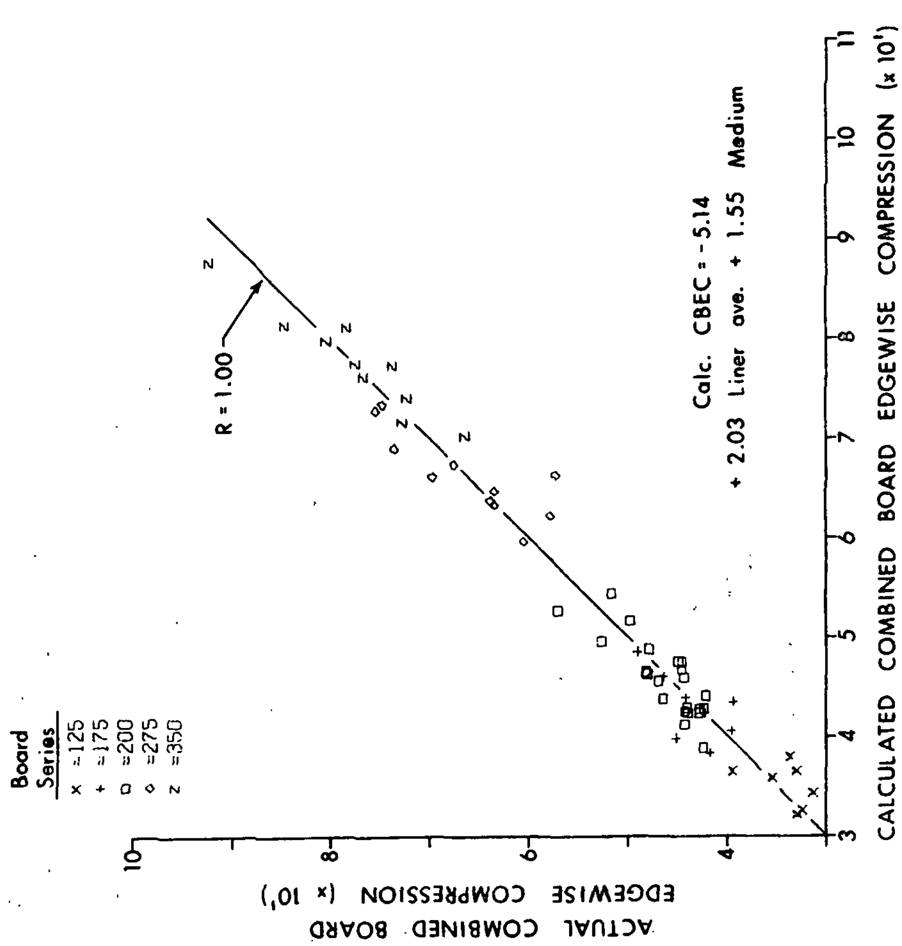

Figure 30. Calculated Versus Actual Combined Board Edgewise Compression for Modified Ring Crush Test

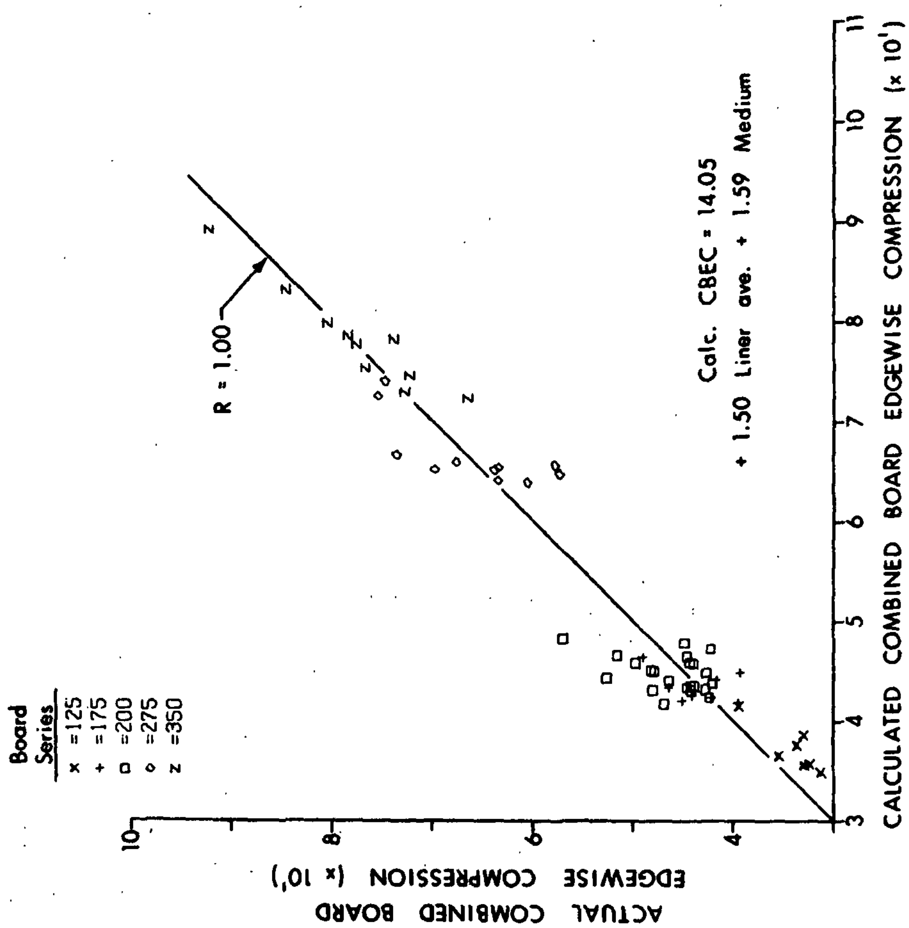

Figure 31. Calculated Versus Actual Combined Board Edgewise Compression for LECT/CFC Tests

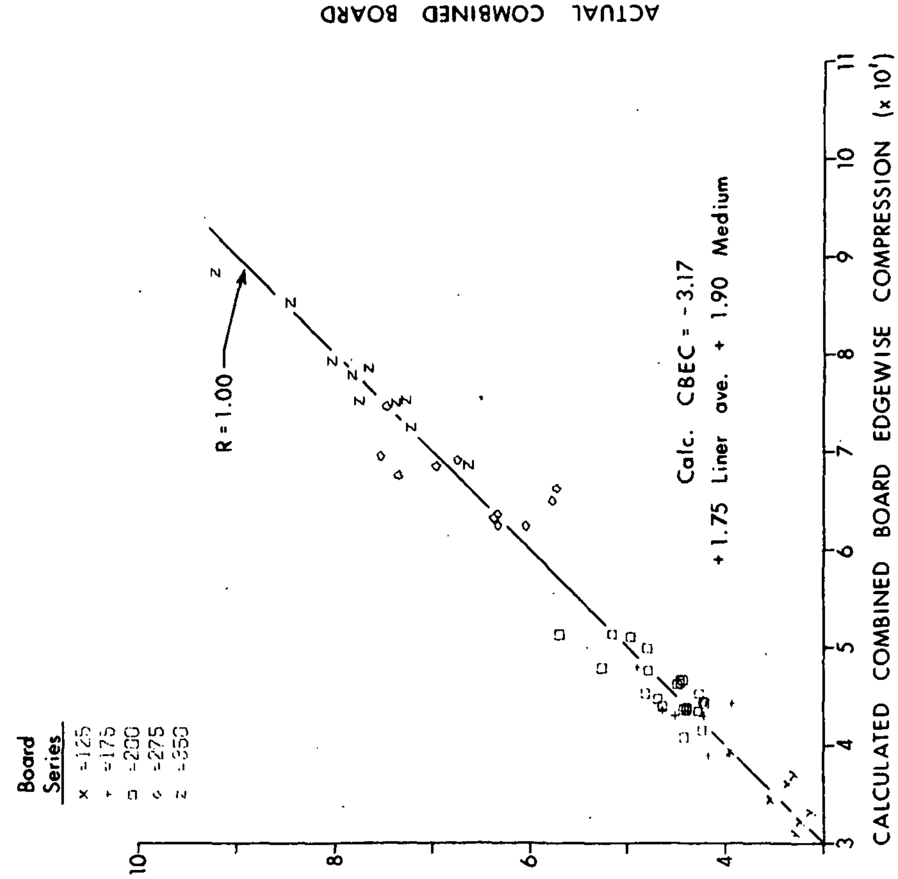

Figure 32. Calculated Versus Actual Combined Board Edgewise Compression for FPL Test

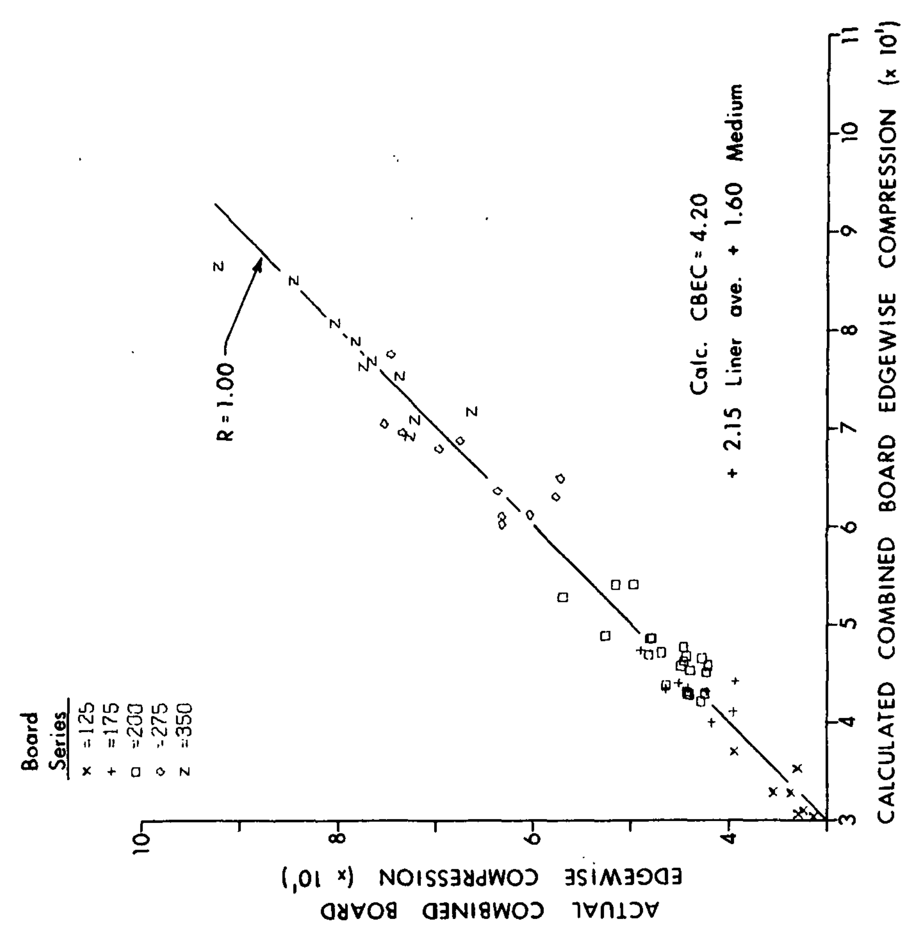

Figure 33. Calculated Versus Actual Combined Board Edgewise Compression for Weyerhaeuser Test

COMPARISON OF EASE OF TEST USAGE

In terms of ease of test usage, each test has its own advantages and disadvantages. The table below lists the approximate test time to run 10 specimens in each test.

	Approx. Test Time per 10 Spec., min[a]
Regular ring[c]	4-5
Modified ring[c]	10-11[b]
Liner Edge Crush (LECT)[c]	4-5
Concora Fluted Crush[c]	4-5
FPL (Instron)	40[d]
Weyerhaeuser (Instron)	30

[a]Excluding specimen cutting.
[b]Including waxing edges and forming.
[c]On H&D tester at 25 lb/sec.
[d]Time will vary somewhat depending on specimen behavior.

The short time required for the regular ring, LECT and CFC tests makes them more suited to quality control work where quick results are needed. The addition of the moisture correction device on the LECT as mentioned under that test description could provide an additional quality control feature because samples would not have to be conditioned.

The modified ring test takes more time to run than the regular ring because the sample preparation is more involved.

Both the FPL test and Weyerhaeuser test are more complicated to run and require the slower operating rates of the Instron tester.

Sample preparation for the FPL test requires a paper cutter with a fixed positive stop for paper positioning in order to insure that specimen widths do not vary. The Weyerhaeuser test does not have that problem because of the special die provided. The running time for the FPL and Weyerhaeuser tests is about the same, but there are more steps involved in the Weyerhaeuser test and, therefore, more chances for error.

Some samples were run in the FPL test on the H&D compression tester to judge its value in obtaining maximum load values only. Very good concentration was required by an experienced operator to pick up the failure point on the dial indicator as it moved. This was only achieved after a session in which the operator was allowed to use a transducer and X-Y plotter to graph the load *versus* time curve for an instantaneous feedback of his accuracy in reading the gage. This allowed him to build confidence in his judgment.

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THE INSTITUTE OF PAPER CHEMISTRY

Gerald R. Kloth
Research Fellow

William J. Whitsitt
Research Associate

Terrence S. Fox
Director
Container Division

APPENDIX

TABLE XI

LINERBOARD EDGEWISE COMPRESSION TEST RESULTS ON 125-LB SERIES SAMPLES

Mill Code	Sample No. Comb. Board	Sample No. Liner	Basis Weight, lb/M ft^2	Caliper, pt.	Maximum Load, lb/inch: Reg. Ring Comp.	Mod. Ring Comp.	Liner Edge Crush (LECT)	FPL Comp.	Weyer-haeuser Comp.	Coefficient of Variation, %: Reg. Ring Comp.	Mod. Ring Comp.	Liner Edge Crush (LECT)	FPL Comp.	Weyer-haeuser Comp.
Single-face Liner Samples														
C	1006	1007	27.4	8.0	9.9	12.6	3.8	12.5	8.9	5.0	4.0	7.2	5.2	15.0
E	930	931	27.0	8.5	8.2	12.0	3.2	10.9	8.4	7.0	4.6	3.9	9.6	8.2
G	899	900	28.0	8.9	8.8	13.1	3.7	12.3	8.3	8.0	4.3	5.5	8.2	13.3
H	1034	1035	25.2	8.5	7.8	10.9	3.1	10.3	7.8	6.1	8.3	7.8	17.5	8.7
J	1058	1059	31.5	10.4	10.4	13.6	6.2	15.1	11.9	6.7	5.9	8.8	6.7	12.4
K	875	876	25.8	8.0	7.6	10.7	3.4	10.2	7.6	9.6	6.3	14.6	6.6	10.2
M	990	991	25.3	7.4	8.6	11.6	3.2	10.9	8.2	4.2	4.1	10.4	7.2	12.2
	Av.		--	--	8.8	12.1	3.8	11.7	8.7	6.7	5.4	8.3	8.7	11.5
Double-face Liner Samples														
C	1006	1008	26.2	8.0	8.7	11.4	3.9	11.5	8.4	6.7	10.0	6.0	11.5	13.0
E	930	932	26.8	8.5	8.4	12.2	3.3	10.7	8.0	7.7	2.9	5.9	6.2	9.1
G	899	901	27.5	8.6	9.1	13.0	3.7	12.2	8.5	8.5	6.8	6.1	7.2	13.8
H	1034	1036	25.3	7.9	7.6	11.0	3.2	10.2	7.2	11.2	8.4	8.1	10.9	8.7
J	1058	1060	27.0	8.0	9.1	12.0	4.1	12.4	8.3	3.4	4.8	13.1	6.4	14.2
K	875	877	26.2	8.0	8.0	10.8	3.4	10.4	7.6	7.9	3.9	8.6	4.8	16.3
M	990	992	25.9	7.6	8.0	12.4	3.2	11.5	7.6	9.6	6.7	8.7	7.8	15.4
	Av.		--	--	8.4	11.8	3.5	11.3	8.0	7.9	6.2	8.1	7.8	12.9
Overall av.			--	--	8.6	12.0	3.6	11.5	8.4	7.3	5.8	8.2	8.2	12.2

Note: The ring and liner edge crush tests were carried out on an H&D tester at a test rate of 25 lb/sec. The FPL and Weyerhaeuser tests were carried out on an Instron tester using rates of 0.02 and 0.08 inch/min as per instructions.

TABLE XII

LINERBOARD EDGEWISE COMPRESSION TEST RESULTS ON 175-LB SERIES SAMPLES

Mill Code	Sample No.		Basis Weight, lb/M ft^2	Caliper, pt.	Maximum Load, lb/inch					Coefficient of Variation, %				
	Comb. Board	Liner			Reg. Ring Comp.	Mod. Ring Comp.	Liner Edge Crush (LECT)	FPL Comp.	Weyer-haeuser Comp.	Reg. Ring Comp.	Mod. Ring Comp.	Liner Edge Crush (LECT)	FPL Comp.	Weyer-haeuser Comp.
					Single-face Liner Samples									
A	1090	1091	33.2	9.4	11.9	14.3	5.7	15.4	12.3	4.8	5.8	6.5	7.1	12.4
B	962	963	34.2	9.6	12.0	15.2	5.7	14.0	11.7	3.3	3.2	8.6	6.6	4.3
C	1010	1011	33.6	11.1	9.5	12.2	5.2	12.2	9.7	7.7	6.7	7.7	7.0	13.6
G	891	892	32.7	10.6	11.4	15.0	5.6	14.5	10.5	8.6	6.8	9.0	14.1	15.4
I	946	947	40.8	11.9	12.3	15.1	6.5	14.3	12.1	7.7	3.5	5.2	7.2	9.6
J	1062	1063	33.9	11.4	11.7	14.6	6.9	14.3	12.0	6.0	7.3	8.9	6.9	9.7
K	879	880	38.8	11.5	15.0	17.0	7.4	16.1	12.2	2.6	6.6	8.4	6.9	13.0
M	994	995	33.3	11.0	11.7	14.4	6.4	14.2	11.5	5.6	4.6	6.2	7.4	4.3
	Av.		--	--	12.0	14.7	6.2	14.4	11.5	5.8	5.6	7.6	7.9	10.3
					Double-face Liner Samples									
A	1090	1092	41.5	12.9	12.7	14.5	7.7	15.8	14.4	5.6	2.8	10.9	7.4	4.6
B	962	964	42.8	13.6	17.0	18.9	9.7	18.7	16.5	3.7	2.7	6.5	4.0	8.4
C	1010	1012	45.3	12.8	15.1	16.8	8.5	17.5	14.5	5.1	4.1	9.1	8.1	8.1
G	891	893	41.9	12.3	14.0	16.1	8.3	17.1	13.7	6.2	6.9	8.2	9.0	8.2
I	946	948	40.3	11.9	11.9	14.2	6.6	14.8	12.1	3.5	4.3	6.5	5.3	9.4
J	1062	1064	33.9	10.4	9.0	11.2	5.7	11.8	9.3	9.4	8.2	7.8	10.5	9.8
K	879	881	39.2	11.2	13.9	16.4	7.0	15.5	13.5	6.6	3.8	6.2	9.3	7.6
M	994	996	42.5	12.2	15.1	16.4	7.9	17.2	14.7	5.4	4.7	7.3	8.8	6.7
	Av.		--	--	13.6	15.6	7.7	16.0	13.6	5.7	4.7	7.8	7.8	7.9
Overall av.			--	--	12.8	15.2	7.0	15.2	12.6	5.8	5.2	7.7	7.8	9.1

Note: The ring and liner edge crush tests were carried out on an H&D tester at a test rate of 25 lb/sec. The FPL and Weyerhaeuser tests were carried out on an Instron tester using rates of 0.02 and 0.08 inch/min as per instructions.

TABLE XIII

LINERBOARD EDGEWISE COMPRESSION TEST RESULTS ON 200-LB SERIES SAMPLES

Mill Code	Sample No. Comb. Board	Sample No. Liner	Basis Weight, lb/M ft²	Caliper, pt.	Maximum Load, lb/inch: Reg. Ring Comp.	Maximum Load: Mod. Ring Comp.	Maximum Load: Liner Edge Crush (LECT)	Maximum Load: FPL Comp.	Maximum Load: Weyer-haeuser Comp.	Coefficient of Variation, %: Reg. Ring Comp.	C.V.: Mod. Ring Comp.	C.V.: Liner Edge Crush (LECT)	C.V.: FPL Comp.	C.V.: Weyer-haeuser Comp.
						Single-face Liner Samples								
A	1094	1095	42.8	12.8	12.6	15.0	7.5	15.3	13.7	5.4	5.0	12.4	6.8	6.6
A	1098	1099	42.7	13.1	13.7	16.0	8.4	18.0	14.1	5.0	4.8	11.4	8.2	8.5
B	950	951	44.3	13.9	20.8	21.5	11.8	22.4	18.7	3.8	4.0	7.2	5.9	15.9
B	958	959	44.7	12.1	17.1	18.7	9.3	19.1	16.1	4.2	4.0	5.6	2.7	14.6
C	1002	1003	41.8	12.6	13.0	14.8	6.8	14.6	12.0	5.5	6.8	7.9	6.7	8.6
C	1022	1023	41.7	12.2	14.0	16.2	8.3	17.0	13.7	4.0	3.8	8.0	9.0	10.7
D	970	971	41.7	11.8	12.6	14.5	7.0	14.9	12.2	4.1	4.8	11.2	8.9	9.0
D	986	987	42.6	12.0	18.0	20.2	8.8	19.9	17.5	5.3	3.0	6.2	5.3	6.8
E	926	927	44.0	12.7	14.2	16.2	7.8	16.1	13.7	5.7	7.1	10.6	8.9	10.4
E	942	943	44.3	11.8	15.6	16.6	7.2	16.6	14.6	7.0	3.6	7.8	8.7	8.7
F	1078	1079	41.7	12.1	13.1	16.0	8.2	16.0	13.8	8.7	10.9	12.5	9.3	6.7
G	895	896	42.4	11.0	16.6	18.1	7.1	18.6	15.1	3.7	3.8	4.3	4.9	8.4
G	907	908	42.5	14.4	16.1	18.3	10.7	19.4	16.5	4.7	5.8	7.0	8.0	4.7
H	1030	1031	42.7	13.0	13.6	15.9	8.7	17.5	13.9	3.7	6.9	5.3	6.1	7.5
H	1050	1051	43.7	14.0	14.0	17.6	9.6	18.7	14.2	3.5	6.5	6.6	10.9	5.4
I	849	850	42.6	12.2	15.8	18.0	8.2	17.6	14.8	5.5	4.2	4.8	11.5	7.1
I	853	854	41.5	12.0	15.2	16.9	8.0	16.7	14.5	4.2	6.3	6.8	7.1	4.4
J	1054	1055	42.5	12.9	12.8	14.6	8.4	15.6	13.2	7.4	8.7	9.1	12.6	7.4
J	1074	1075	41.4	12.9	11.8	14.2	7.9	14.4	11.1	7.2	5.3	6.9	8.4	10.4
K	871	872	41.9	13.0	13.2	15.6	8.2	14.7	12.5	10.7	8.9	12.3	15.1	17.6
K	887	888	40.5	11.8	13.0	15.6	7.1	14.7	12.9	6.1	4.9	8.2	10.0	6.9
H	1038	1039	41.8	13.3	13.6	16.0	8.2	15.7	13.4	5.8	4.6	5.2	11.0	8.9
	Av.		--	--	14.6	16.7	8.3	17.0	14.2	5.5	5.6	8.1	8.4	8.9
						Double-face Liner Samples								
A	1094	1096	41.1	13.0	11.7	14.4	7.5	14.8	12.5	2.9	5.5	8.1	5.1	7.3
A	1098	1100	43.0	12.6	12.4	14.4	7.3	14.4	12.3	7.8	8.5	10.0	7.0	6.9
B	950	952	43.9	13.3	16.0	18.2	9.6	17.2	15.6	5.6	5.6	7.2	10.1	6.2
B	958	960	44.0	12.2	17.8	19.3	9.8	19.1	17.1	4.8	3.2	3.6	7.3	8.8
C	1002	1004	41.9	12.2	13.6	14.9	6.7	15.4	12.1	8.3	4.8	9.6	9.8	13.0
C	1022	1024	43.1	11.8	14.8	16.4	7.9	17.0	15.1	4.4	5.2	6.2	5.8	5.6
D	970	972	43.6	12.6	14.7	16.7	8.8	17.5	15.0	5.0	4.8	14.0	8.4	8.2
D	986	988	42.8	12.0	18.5	20.9	9.8	20.1	17.9	5.3	3.8	5.5	6.7	7.4
E	926	928	42.7	10.9	16.4	17.9	6.8	18.8	15.1	6.0	3.7	3.9	7.9	6.8
E	942	944	42.2	11.1	15.2	17.5	7.0	17.5	15.0	5.0	4.5	6.0	5.5	5.5
F	1078	1080	42.7	11.5	14.7	17.1	7.6	18.2	15.2	5.8	4.1	10.0	5.4	5.0
G	895	897	42.8	11.0	16.4	17.7	7.6	16.8	14.9	6.4	5.4	9.3	6.4	5.5
G	907	909	42.8	14.2	13.8	16.8	8.7	16.7	14.0	6.5	4.0	7.4	7.2	5.5
H	1030	1032	43.0	13.1	14.4	16.4	8.8	17.8	14.8	4.5	3.2	10.4	8.0	6.5
H	1050	1052	43.4	13.7	14.3	17.7	9.8	18.5	14.7	4.4	7.7	11.8	8.3	10.3
I	849	851	41.3	11.9	15.3	18.0	8.0	18.6	15.9	7.3	5.0	9.2	7.5	7.9
I	853	855	41.5	12.0	14.3	16.2	7.9	17.2	14.0	4.0	2.6	6.4	6.6	4.4
J	1054	1056	41.4	13.0	12.7	14.8	8.4	15.6	14.0	8.3	7.6	4.0	6.4	4.2
J	1074	1076	41.8	12.5	14.2	17.0	8.6	16.2	14.4	5.7	3.8	6.7	6.8	5.9
K	871	873	43.4	12.9	14.6	16.2	8.8	16.0	13.6	6.0	3.6	7.4	9.4	10.3
K	887	889	41.8	12.3	13.4	15.6	7.5	15.1	13.0	5.9	5.7	8.1	5.7	8.8
H	1038	1040	42.7	13.0	14.7	16.7	8.5	18.6	13.3	4.2	5.1	6.4	9.0	12.2
	Av.		--	--	14.7	16.8	8.3	17.2	14.5	5.6	4.9	7.8	7.3	7.4
Overall av.			--	--	14.6	16.8	8.3	17.1	14.4	5.6	5.2	8.0	7.8	8.2

Note: The ring and liner edge crush tests were carried out on an H&D tester at a test rate of 25 lb/sec. The FPL and Weyerhaeuser tests were carried out on an Instron tester using rates of 0.02 and 0.08 inch/min as per instructions.

TABLE XIV

LINERBOARD EDGEWISE COMPRESSION TEST RESULTS ON 275-LB SERIES SAMPLES

Mill Code	Sample No. Comb. Board	Sample No. Liner	Basis Weight, lb/M ft²	Caliper, pt.	Maximum Load, lb/inch: Reg. Ring Comp.	Mod. Ring Comp.	Liner Edge Crush (LECT)	FPL Comp.	Weyer-haeuser Comp.	Coefficient of Variation, %: Reg. Ring Comp.	Mod. Ring Comp.	Liner Edge Crush (LECT)	FPL Comp.	Weyer-haeuser Comp.
					Single-face Liner Samples									
A	1102	1103	68.8	18.5	17.4	22.6	16.9	24.2	18.5	4.8	4.2	8.0	7.1	7.4
B	954	955	69.0	21.1	26.8	29.8	26.7	30.3	24.9	3.2	3.9	6.7	7.8	5.5
C	1014	1015	70.2	19.8	23.0	27.8	22.1	29.8	23.1	4.0	3.0	4.4	5.9	5.7
D	978	979	72.6	20.8	26.9	29.3	26.2	31.2	28.9	6.4	5.6	5.6	12.3	6.8
E	934	935	66.2	18.9	26.6	28.6	22.7	29.5	24.5	3.9	3.8	3.7	7.7	3.5
F	1082	1083	68.1	19.2	21.5	25.6	21.4	27.6	23.2	5.1	6.8	4.9	12.4	8.6
G	903	904	68.8	20.1	24.1	25.3	22.6	28.1	22.6	4.5	3.7	5.8	10.0	7.8
H	1042	1043	69.6	18.0	24.4	27.9	22.2	30.6	26.1	4.6	2.7	4.6	10.8	7.3
J	1066	1067	68.0	20.1	20.0	24.6	20.3	27.5	21.1	6.3	5.7	3.2	6.4	4.5
K	883	884	69.0	19.8	24.8	26.3	22.8	29.3	23.6	6.2	4.4	7.9	6.2	7.6
M	998	999	69.1	20.6	21.5	25.5	21.3	26.3	21.0	2.4	4.0	4.3	5.4	13.1
	Av.		--	--	23.4	26.6	22.3	28.6	23.4	4.7	4.3	5.4	8.4	7.1
					Double-face Liner Samples									
A	1102	1104	67.0	20.2	19.1	24.1	20.5	27.7	22.3	7.8	7.1	7.8	8.1	6.4
B	954	956	69.4	21.1	26.1	28.9	25.3	29.3	24.8	4.3	5.4	6.6	4.9	6.7
C	1014	1016	67.6	18.2	20.5	24.2	19.8	26.4	20.9	5.0	4.9	4.7	4.7	5.9
D	978	980	74.0	20.8	26.9	29.8	27.6	33.8	27.0	3.5	1.5	5.2	5.8	3.9
E	934	936	68.5	19.2	24.8	27.9	24.4	30.3	26.3	2.7	2.8	4.6	7.3	5.0
F	1082	1084	69.1	17.1	27.1	29.2	22.7	32.1	24.3	3.4	3.5	6.1	8.3	16.4
G	903	905	69.1	18.6	24.1	26.0	21.4	27.3	20.6	4.0	4.2	2.8	7.9	7.2
H	1042	1044	69.0	18.2	23.4	27.8	22.4	31.1	24.6	2.2	4.2	4.9	11.7	5.6
J	1066	1068	67.2	20.2	19.2	23.8	20.3	25.4	20.8	7.0	3.1	2.4	9.7	9.0
K	883	885	69.3	19.7	24.1	26.3	22.5	27.4	22.9	4.9	3.9	6.7	10.6	9.2
M	998	1000	69.0	19.9	24.0	27.3	22.6	28.6	22.6	4.3	4.7	5.3	7.4	7.6
	Av.		--	--	23.6	26.8	22.7	29.0	23.4	4.5	4.1	5.2	7.8	7.5
Overall av.			--	--	23.5	26.7	22.5	28.8	23.4	4.6	4.2	5.3	8.1	7.3

Note: The ring and liner edge crush tests were carried out on an H&D tester at a test rate of 25 lb/sec. The FPL and Weyerhaeuser tests were carried out on an Instron tester using rates of 0.02 and 0.08 inch/min as per instructions.

TABLE XV

LINERBOARD EDGEWISE COMPRESSION TEST RESULTS ON 350-LB SERIES SAMPLES

Mill Code	Sample No. Comb. Board	Sample No. Liner	Basis Weight, lb/M ft²	Caliper, pt.	Maximum Load, lb/inch: Reg. Ring Comp.	Mod. Ring Comp.	Liner Edge Crush (LECT)	FPL Comp.	Weyer-haeuser Comp.	Coefficient of Variation, %: Reg. Ring Comp.	Mod. Ring Comp.	Liner Edge Crush (LECT)	FPL Comp.	Weyer-haeuser Comp.
					Single-face Liner Samples									
B	966	967	89.3	24.2	28.4	31.1	27.4	34.9	26.4	4.7	3.8	6.8	6.8	4.7
C	1018	1019	86.9	24.7	24.8	31.4	27.8	34.9	27.6	3.5	4.4	4.3	6.6	5.6
D	982	983	90.6	26.0	28.1	32.2	30.9	34.8	29.0	5.0	4.7	5.9	8.9	7.6
E	938	939	89.6	24.4	30.1	33.5	30.7	36.3	29.5	5.4	5.9	3.2	9.8	4.8
F	1086	1087	91.6	27.1	26.7	33.4	30.5	36.7	29.1	4.3	4.5	5.4	6.8	6.7
G	911	912	92.1	25.0	27.9	31.0	29.4	34.1	26.5	3.4	3.4	4.0	9.4	7.6
H	1046	1047	89.9	27.0	29.3	34.5	34.5	40.2	33.0	2.5	4.8	3.8	7.1	6.0
J	1070	1071	86.9	24.8	25.1	31.9	29.0	31.9	26.8	6.6	5.0	5.6	11.2	6.7
K	922	923	93.8	25.7	28.2	32.4	29.8	36.8	30.2	4.1	3.9	4.4	9.4	4.1
M	1026	1027	90.7	25.8	27.3	32.7	31.9	34.0	27.7	4.8	3.9	6.8	10.1	18.8
	Av.		--	--	27.6	32.4	30.2	35.5	28.6	4.4	4.4	5.0	8.6	7.2
					Double-face Liner Samples									
B	966	968	89.0	24.5	23.3	26.6	24.2	30.7	22.7	6.0	4.1	3.3	5.0	6.4
C	1018	1020	88.7	24.5	25.7	32.0	28.5	36.4	28.9	4.7	4.0	6.1	6.7	11.8
D	982	984	91.4	26.7	27.8	33.2	30.1	34.3	28.6	4.2	3.0	4.0	10.8	3.5
E	938	940	88.9	24.2	30.9	34.0	31.4	35.0	29.6	4.0	6.0	7.4	9.7	10.5
F	1086	1088	93.9	27.4	26.4	33.5	29.7	34.1	31.0	3.5	3.6	6.0	10.1	6.4
G	911	913	88.4	25.2	27.4	31.2	28.7	33.3	26.7	2.9	5.2	2.6	5.5	6.5
H	1046	1048	91.6	26.9	29.9	35.8	33.5	39.8	32.1	2.8	3.3	5.3	5.6	8.2
J	1070	1072	89.1	26.4	25.5	29.8	28.6	33.1	27.8	4.6	5.0	6.7	9.2	4.6
K	922	924	88.2	25.6	29.5	32.4	30.0	34.0	27.6	4.3	3.4	5.9	10.8	3.3
M	1026	1028	91.5	26.2	28.0	33.2	31.9	35.6	28.9	2.9	5.3	5.5	7.5	12.8
	Av.		--	--	27.4	32.2	29.6	34.6	28.4	4.0	4.3	5.3	8.1	7.4
Overall av.			--	--	27.5	32.3	29.9	35.0	28.5	4.2	4.4	5.2	8.4	7.3

Note: The ring and liner edge crush tests were carried out on an H&D tester at a test rate of 25 lb/sec. The FPL and Weyerhaeuser tests were carried out on an Instron tester using rates of 0.02 and 0.08 inch/min as per instructions.

TABLE XVI

EDGEWISE COMPRESSION TEST RESULTS ON CORRUGATING MEDIUMS USED IN 125-LB SERIES SAMPLES

Mill Code	Sample No. Comb. Board	Sample No. Medium	Basis Weight, lb/M ft^2	Caliper, pt.	Maximum Load, lb/inch: Reg. Ring Comp.[a]	Mod. Ring Comp.[a]	Concora Fluted Crush[a,b]	FPL Comp.[c]	Weyerhaeuser Comp.[c]	Coefficient of Variation, %: Reg. Ring Comp.	Mod. Ring Comp.	Concora Fluted Crush	FPL Comp.	Weyerhaeuser Comp.
C	1006	1009	26.7	10.1	7.5	11.2	11.8	10.1	7.8	7.4	5.6	3.5	5.4	7.0
E	930	933	26.9	10.5	6.5	10.6	11.0	9.8	6.9	7.4	3.7	3.6	7.4	6.2
G	899	902	26.2	8.8	6.2	10.7	11.3	9.4	6.6	5.8	4.5	3.2	8.4	6.8
H	1034	1037	27.4	12.1	6.2	10.0	10.6	9.2	6.7	8.5	2.8	3.2	7.6	14.1
J	1058	1061	25.8	9.6	6.3	10.1	12.4	9.7	6.9	8.2	5.1	6.9	4.7	10.1
K	875	878	26.3	8.8	5.8	10.0	10.3	8.5	6.3	8.2	4.4	3.3	6.1	6.0
M	990	993	26.2	10.2	6.3	9.6	10.0	8.8	5.8	6.7	4.3	3.7	5.6	18.2
	Av.		--	--	6.4	10.3	11.1	9.4	6.7	7.4	4.4	3.9	6.4	9.8

[a]Tested on H&D tester at 25 lb/sec.
[b]Tested immediately after fluting.
[c]Tested on Instron tester.

TABLE XVII

EDGEWISE COMPRESSION TEST RESULTS ON CORRUGATING MEDIUMS USED IN 175-LB SERIES SAMPLES

Mill Code	Sample No.		Basis Weight, lb/M ft²	Caliper, pt.	Maximum Load, lb/inch					Coefficient of Variation, %				
	Comb. Board	Medium			Reg. Ring Comp.[a]	Mod. Ring Comp.[a]	Concora Fluted Crush[a,b]	FPL Comp.[c]	Weyer-haeuser Comp.[c]	Reg. Ring Comp.	Mod. Ring Comp.	Concora Fluted Crush	FPL Comp.	Weyer-haeuser Comp.
A	1090	1093	26.2	10.4	6.1	10.2	11.3	10.0	6.9	6.7	4.1	4.5	5.1	3.9
B	962	965	32.7	9.9	7.8	12.2	13.1	11.8	8.0	8.3	5.2	3.8	5.2	5.0
C	1010	1013	26.3	10.2	7.6	12.4	12.9	11.3	8.7	4.8	4.7	8.1	6.3	9.1
G	891	894	27.6	12.4	8.0	11.3	11.3	10.0	9.3	4.3	3.1	5.2	3.4	5.9
I	946	949	26.6	10.0	7.0	10.3	11.2	8.9	6.8	7.1	4.1	5.2	7.3	6.5
J	1062	1065	28.4	10.0	7.9	11.2	12.9	10.2	8.1	7.2	6.4	5.3	8.3	4.5
K	879	882	26.6	10.4	7.0	11.1	11.6	10.1	7.3	6.8	5.9	4.5	7.1	11.3
M	994	997	27.1	10.5	6.6	10.4	11.0	9.8	6.8	4.8	6.2	4.7	6.0	6.3
	Av.		--	--	7.3	11.1	11.9	10.3	7.6	6.2	5.0	5.2	6.1	6.6

[a]Tested on H&D tester at 25 lb/sec.

[b]Tested immediately after fluting.

[c]Tested on Instron tester.

TABLE XVIII

EDGEWISE COMPRESSION TEST RESULTS ON CORRUGATING MEDIUMS USED IN 200-LB SERIES SAMPLES

Mill Code	Sample No.		Basis Weight, lb/M ft²	Caliper, pt.	Maximum Load, lb/inch					Coefficient of Variation, %				
	Comb. Board	Medium			Reg. Ring Comp.[a]	Mod. Ring Comp.[a]	Concora Fluted Crush[a,b]	FPL Comp.[c]	Weyer-haeuser Comp.[c]	Reg. Ring Comp.	Mod. Ring Comp.	Concora Fluted Crush	FPL Comp.	Weyer-haeuser Comp.
A	1094	1097	26.5	11.4	6.0	9.2	10.7	9.7	6.6	5.2	5.2	4.2	7.1	10.0
A	1098	1101	25.8	10.1	6.3	10.0	11.2	9.8	6.6	5.9	3.3	4.3	7.1	11.3
B	950	953	25.9	9.7	7.3	11.2	11.4	10.5	7.3	9.2	8.2	4.7	5.3	9.3
B	958	961	25.4	10.0	6.8	11.7	11.0	11.0	8.9	6.6	4.1	6.6	6.8	6.9
C	1002	1005	26.0	9.1	7.0	11.2	11.9	10.7	7.6	7.9	5.6	4.2	3.2	8.6
C	1022	1025	25.5	9.7	6.4	10.4	11.0	9.4	6.6	7.3	4.6	5.8	8.1	7.0
D	970	973	25.8	11.2	6.6	10.2	11.0	9.8	7.4	5.4	5.3	5.0	8.1	7.9
D	986	989	26.4	11.2	7.3	11.5	11.7	10.3	7.3	6.7	5.8	5.8	6.2	8.0
E	926	929	26.5	10.6	6.8	11.1	11.5	10.0	6.9	8.5	5.9	4.5	5.0	6.2
E	942	945	26.1	9.8	6.6	10.4	10.6	9.6	6.9	4.5	5.0	3.2	5.8	12.2
F	1078	1081	26.2	9.2	7.4	11.6	10.8	12.2	8.3	8.0	7.2	2.4	7.7	8.1
G	895	898	26.4	10.6	7.4	11.8	12.1	10.6	7.7	5.0	4.5	5.1	5.6	8.3
G	907	910	26.4	9.2	6.6	11.0	11.2	9.6	6.7	5.8	5.2	4.9	7.2	6.6
H	1030	1033	27.4	11.9	6.0	9.7	11.0	9.3	7.2	9.7	4.4	4.1	9.8	9.5
H	1050	1053	26.9	11.7	6.0	9.8	10.8	9.0	7.2	6.7	5.9	4.5	8.1	7.6
I	849	852	26.5	9.3	7.4	12.2	11.8	10.1	7.1	3.9	3.8	5.1	5.1	6.0
I	853	856	26.2	9.8	7.8	11.6	12.0	9.9	7.6	5.8	6.7	4.4	8.5	10.9
J	1054	1057	26.6	10.0	6.8	11.7	12.9	10.7	7.3	8.6	6.1	5.7	8.6	7.3
J	1074	1077	25.9	9.8	6.7	10.4	12.2	10.5	7.0	5.3	5.7	4.7	6.6	8.8
K	871	874	26.7	10.0	8.6	13.1	13.2	11.9	8.4	3.8	4.7	5.2	5.5	5.9
K	887	890	26.6	10.8	6.8	10.4	11.3	9.4	6.7	5.9	5.1	3.6	5.7	5.1
H	1038	1041	26.3	10.6	6.3	10.1	11.0	9.1	6.8	5.5	3.1	4.7	6.6	6.3
	Av.		--	--	6.9	10.9	11.5	10.1	7.3	6.4	5.2	4.7	6.7	8.1

[a]Tested on H&D tester at 25 lb/sec.

[b]Tested immediately after fluting.

[c]Tested on Instron tester.

TABLE XIX

EDGEWISE COMPRESSION TEST RESULTS ON CORRUGATING MEDIUMS USED IN 275-LB SERIES SAMPLES

Mill Code	Sample No. Comb. Board	Sample No. Medium	Basis Weight, lb/M ft^2	Caliper, pt.	Maximum Load, lb/inch: Reg. Ring Comp.[a]	Mod. Ring Comp.[a]	Concora Fluted Crush[a,b]	FPL Comp.[c]	Weyerhaeuser Comp.[c]	Coefficient of Variation, %: Reg. Ring Comp.	Mod. Ring Comp.	Concora Fluted Crush	FPL Comp.	Weyerhaeuser Comp.
A	1102	1105	33.4	13.7	9.1	12.8	14.7	12.0	9.3	5.8	4.2	2.7	9.7	10.2
B	954	957	25.5	10.2	7.2	11.8	12.2	10.9	7.9	8.6	7.5	3.8	7.4	4.5
C	1014	1017	26.5	10.1	7.7	12.0	12.1	10.7	8.3	5.6	3.7	3.2	2.6	5.2
D	978	981	27.0	11.2	7.5	12.0	12.4	11.0	8.2	7.4	6.1	4.5	5.0	7.6
E	934	937	25.9	9.6	6.6	10.8	10.8	9.7	6.7	5.0	6.6	3.3	4.0	10.5
F	1082	1085	26.0	10.5	6.6	10.1	11.3	10.3	7.9	5.8	6.1	9.7	7.4	10.7
G	903	906	26.2	8.9	6.3	10.5	11.4	9.7	6.0	7.2	7.1	4.8	15.9	13.0
H	1042	1045	26.9	11.3	6.2	10.2	11.6	9.7	6.2	5.2	4.1	4.0	3.0	13.6
J	1066	1069	26.2	9.4	6.8	10.0	12.1	10.2	7.5	9.8	6.0	4.9	8.2	8.1
K	883	886	26.1	8.6	5.8	10.0	10.7	8.9	5.9	8.0	5.0	5.4	5.5	8.5
M	998	1001	26.6	10.3	6.5	10.4	10.7	9.3	6.2	10.8	5.3	5.9	7.1	9.1
	Av.		--	--	6.9	11.0	11.8	10.2	7.3	7.2	5.6	4.8	6.9	9.2

[a] Tested on H&D tester at 25 lb/sec.
[b] Tested immediately after fluting.
[c] Tested on Instron tester.

TABLE XX

EDGEWISE COMPRESSION TEST RESULTS ON CORRUGATING MEDIUMS USED IN 350-LB SERIES SAMPLES

Mill Code	Sample No. Comb. Board	Sample No. Medium	Basis Weight, lb/M ft^2	Caliper, pt.	Maximum Load, lb/inch: Reg. Ring Comp.[a]	Mod. Ring Comp.[a]	Concora Fluted Crush[a,b]	FPL Comp.[c]	Weyer-haeuser Comp.[c]	Coefficient of Variation, %: Reg. Ring Comp.	Mod. Ring Comp.	Concora Fluted Crush	FPL Comp.	Weyer-haeuser Comp.
B	966	969	25.5	10.1	6.9	11.7	12.7	11.1	7.6	8.7	4.1	4.6	7.1	10.9
C	1018	1021	26.9	9.2	6.7	10.9	11.9	10.2	7.5	8.6	7.4	6.9	9.3	5.9
D	982	985	26.2	12.7	7.4	10.4	11.2	9.5	6.3	7.5	7.3	6.0	11.7	11.1
E	938	941	26.2	10.1	7.1	11.4	11.3	9.9	7.0	6.7	3.5	4.4	6.5	8.1
F	1086	1089	25.9	9.0	7.1	11.0	12.9	10.9	7.4	4.5	7.3	5.6	6.4	9.2
G	911	914	26.4	8.7	6.1	10.3	10.6	8.9	6.0	7.3	6.1	2.2	4.4	9.1
H	1046	1049	27.6	11.9	6.2	9.8	11.4	9.8	6.8	4.5	4.9	3.5	6.8	10.6
J	1070	1073	27.6	10.0	5.6	8.2	9.4	7.9	5.5	6.1	5.9	4.2	4.5	8.3
K	922	925	36.4	14.1	12.6	17.4	19.0	15.6	12.5	3.9	4.8	1.9	2.9	10.0
M	1026	1029	27.6	10.3	6.7	10.0	10.2	9.1	6.3	9.0	5.3	4.8	6.2	9.1
	Av.		--	--	7.2	11.1	12.1	10.3	7.3	6.7	5.7	4.4	6.6	9.2

[a]Tested on H&D tester at 25 lb/sec.
[b]Tested immediately after fluting.
[c]Tested on Instron tester.

TABLE XXI

COMBINED BOARD EDGEWISE COMPRESSION RESULTS
ON 125-LB SERIES SAMPLES

Mill Code	Comb. Board No.	Basis Weight, lb/M ft^2	Caliper, pt.	Edgewise Compression: Max. Load, lb/inch	Edgewise Compression: Coeff. of Var., %
C	1006	96	155	33.0	9.0
E	930	96	155	35.4	4.9
G	899	96	152	33.6	3.9
H	1034	93	155	32.4	4.9
J	1058	100	152	39.4	4.4
K	875	94	148	32.8	4.8
M	990	93	145	31.2	5.4
	Av.	--	--	34.0	5.3

TABLE XXII

COMBINED BOARD EDGEWISE COMPRESSION RESULTS
ON 175-LB SERIES SAMPLES

Mill Code	Comb. Board No.	Basis Weight, lb/M ft^2	Caliper, pt.	Edgewise Compression Max. Load, lb/inch	Edgewise Compression Coeff. of Var., %
A	1090	116	160	45.2	4.0
B	962	121	166	49.0	4.1
C	1010	119	159	39.3	4.7
G	891	118	167	44.2	2.9
I	946	124	162	39.6	4.6
J	1062	110	154	41.7	4.2
K	879	119	155	46.4	3.6
M	994	118	154	42.2	4.2
	Av.	--	--	43.4	4.0

TABLE XXIII

COMBINED BOARD EDGEWISE COMPRESSION RESULTS
ON 200-LB SERIES SAMPLES

Mill Code	Comb. Board No.	Basis Weight, lb/M ft^2	Caliper, pt.	Edgewise Compression: Max. Load, lb/inch	Edgewise Compression: Coeff. of Var., %
A	1094	128	160	42.4	5.2
A	1098	126	161	44.2	5.1
B	950	129	166	57.5	3.0
B	958	128	163	49.8	3.6
C	1002	123	157	42.8	4.4
C	1022	123	157	42.1	3.1
D	970	126	142	44.0	4.8
D	986	126	158	51.6	3.4
E	926	128	161	44.6	4.4
E	942	129	155	46.9	4.5
F	1078	125	154	48.0	6.4
G	895	127	163	52.6	3.6
G	907	126	165	44.6	3.8
H	1030	128	163	42.8	8.8
H	1050	129	166	44.4	6.4
I	849	127	164	47.9	3.4
I	853	125	164	48.2	5.0
J	1054	126	161	42.3	5.8
J	1074	124	161	44.0	6.5
K	871	126	159	45.0	5.2
K	887	126	154	44.2	3.5
H	1038	126	161	46.4	4.6
	Av.	--	--	46.2	4.8

TABLE XXIV

COMBINED BOARD EDGEWISE COMPRESSION RESULTS
ON 275-LB SERIES SAMPLES

Mill Code	Comb. Board No.	Basis Weight, lb/M ft^2	Caliper, pt.	Edgewise Compression Max. Load, lb/inch	Edgewise Compression Coeff. of Var., %
A	1102	190	176	57.8	5.4
B	954	179	176	75.4	3.9
C	1014	176	168	57.4	4.2
D	978	187	173	74.8	4.7
E	934	179	172	73.6	3.2
F	1082	194	177	69.8	2.6
G	903	179	169	63.4	3.5
H	1042	181	176	67.6	4.5
J	1066	177	168	60.5	4.3
K	883	181	166	63.8	4.6
M	998	180	172	63.4	4.7
	Av.	--	--	66.1	4.1

TABLE XXV

COMBINED BOARD EDGEWISE COMPRESSION RESULTS
ON 350-LB SERIES SAMPLES

Mill Code	Comb. Board No.	Basis Weight, lb/M ft^2	Caliper, pt.	Edgewise Compression	
				Max. Load, lb/inch	Coeff. of Var., %
B	966	220	181	72.8	3.5
C	1018	218	178	76.7	7.5
D	982	222	184	77.6	4.5
E	938	224	179	78.4	3.3
F	1086	222	181	80.4	4.3
G	911	219	180	72.2	3.7
H	1046	226	190	84.6	4.8
J	1070	218	178	66.4	4.5
K	922	234	187	92.3	3.9
M	1026	224	180	73.8	6.2
	Av.	--	--	77.5	4.6